Estimating MEDICANE Wind and Rainfall Risk in a Changing Climate using a Regionally-Adapted Statistical-Deterministic Approach

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...Let's START with our JCLI-ARTICLE

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Climate Change and Hurricane-Like Extratropical Cyclones: Projections for North Atlantic Polar Lows and Medicanes Based on CMIP5 Models

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ABSTRACT

A novel statistical–deterministic method is applied to generate thousands of synthetic tracks of North Atlantic (NA) polar lows and Mediterranean hurricanes ("medicanes"); these synthetic storms are compatible with the climates simulated by 30 CMIP5 models in both historical and RCP8.5 simulations for a recent (1986–2005) and a future (2081–2100) period, respectively. Present-to-future multimodel mean changes in storm risk are analyzed, with special attention to robust patterns (in terms of consensus among individual models) and privileging in each case the subset of models exhibiting the highest agreement with the results yielded by two reanalyses. A reduction of about 10%–15% in the overall frequency of NA polar lows that would uniformly affect the full spectrum of storm intensities is expected. In addition, a very robust regional redistribution of cases is obtained, namely a tendency to shift part of the polar low activity from the south Greenland–Icelandic sector toward the Nordic seas closer to Scandinavia. In contrast, the future change in the number of medicanes is unclear (on average the total frequency of storms does not vary), but a profound reshaping of the spectrum of lifetime maximum winds is found; the results project a higher number of moderate and violent medicanes at the expense of weak storms. Spatially, the method projects an increased occurrence of medicanes in the western Mediterranean and Black Sea that is balanced by a reduction of storm tracks in contiguous areas, particularly in the central Mediterranean; however, future extreme events (winds > 60 kt; 1 kt = 0.51 m s^{-1}) become more probable in all Mediterranean subbasins.

1. Introduction

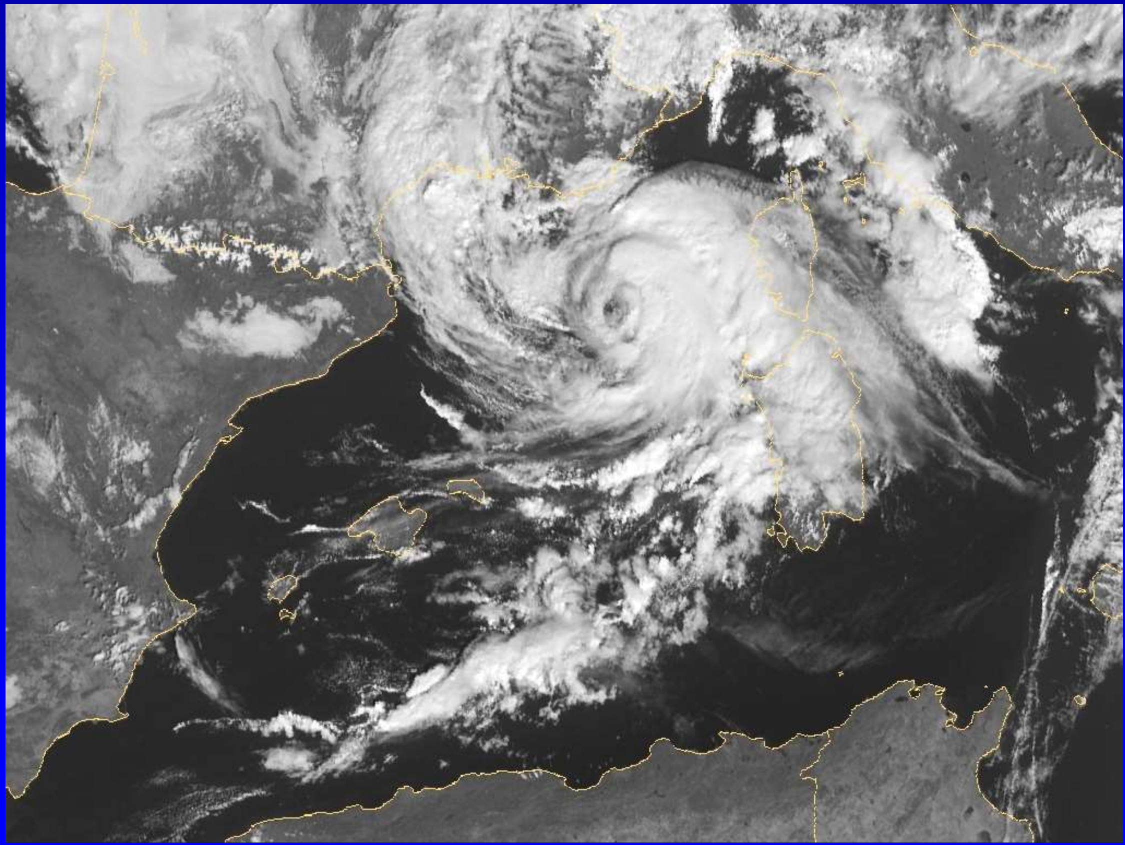
Climate change adaptation strategies demand an analysis of the magnitude of the possible impacts on

examples of mesoscale maritime extratropical storms that from a physical point of view may operate much as tropical cyclones (Emanuel and Rotunno 1989; Emanuel

MOTIVATION

***Medicanes* are physically analogous to tropical cyclones (warm-core, surface flux-driven). These *extreme windstorms* pose serious *threat to* the affected islands and coastal regions and can adversely affect open sea activities such as fishing, cruises and recreational boating:**

- ***Future changes* in frequency, intensity or regional variability *?***
- ***No systematic effort to answer this question in the context of CMIP5***



THIS WORK: Statistical-deterministic approach

Developed by Emanuel at MIT in the context of the long-term wind risk associated with tropical cyclones:

- ***Low-cost generation of thousands of synthetic storms***
- ***Statistically robust assessment of risk (e.g. return periods for winds)***

- ***Genesis: Random draws from observed PDF or Random seeding***
- ***Track: Randomly varying synthetic winds (respecting climatology)***
- ***Environment: Previous winds + monthly-mean thermodynamic fields***
- ***Intensity and radial distribution of winds: CHIPS model***

ADAPTATION OF THE METHOD

The separation of timescales made in the tropics between the synthetic wind field (fast scale) and the thermodynamic environment (slow scale) is not appropriate to represent the movement, growth and decay of mid-latitude weather systems. In addition, existing data of medicane genesis is too sparse to form a reasonable PDF of genesis, and random seeding would be very inefficient:

- ***For each month, decomposition through PCA of 10-day synoptic evolutions of z250, z850, T600, R600 and PINT into the new space of independent PCs***
- ***Random selection + random perturbation of the set of PCs***
- ***This perturbed set of PCs is converted back into physical space***
- ***This is tantamount to generating 10-day sequences of spatiotemporal coherent z250, z850, T600, R600 and PINT synthetic fields which also respect their mutual covariances***

- ***Potential Genesis: Based on the GENIX parameter***

• Application of an **empirical index of genesis:**

$$I = \left|10^5 \eta\right|^{3/2} \left(\frac{H}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 \left(1 + 0.1 V_{shear}\right)^{-2},$$

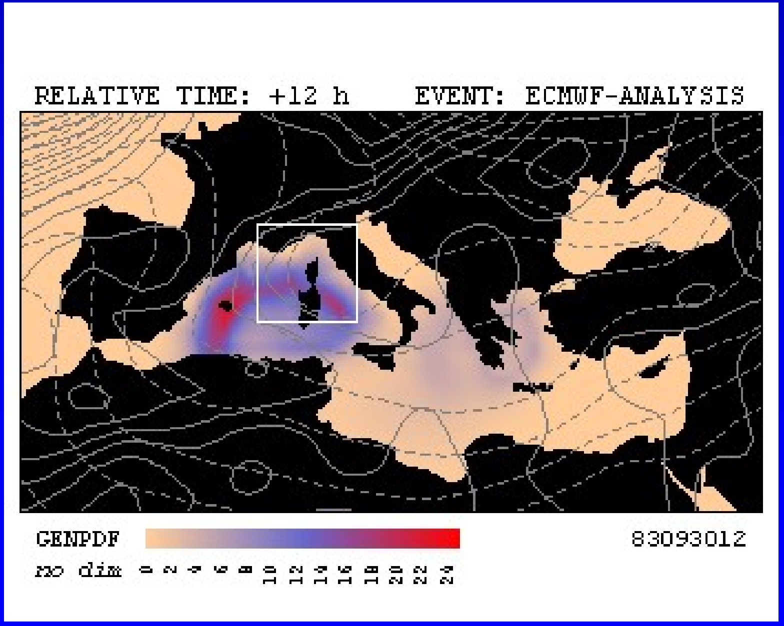
GENIX parameter
(Emanuel and Nolan, 2004)

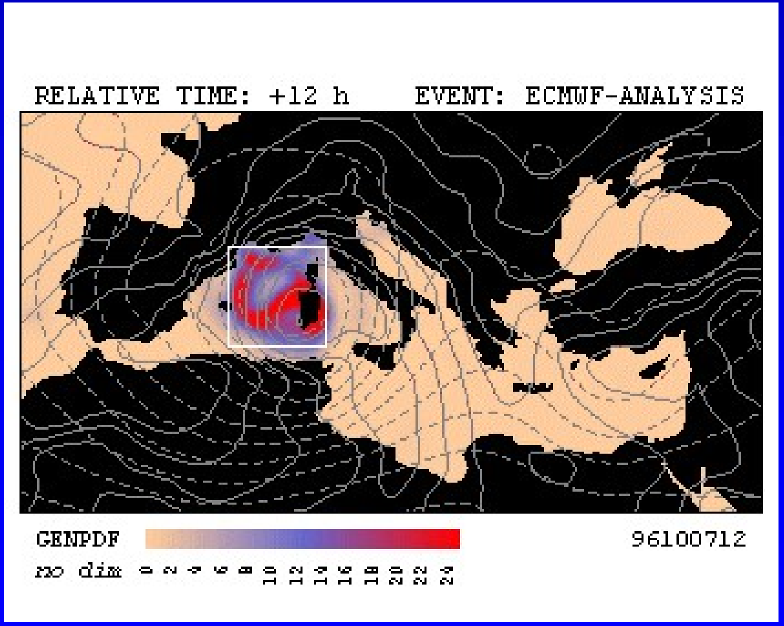
$\eta \equiv 850\, hPa\ absolute\ vorticity\ (s^{-1})$,

$H \equiv 600\, mb\ relative\ humidity\ (\%)$,

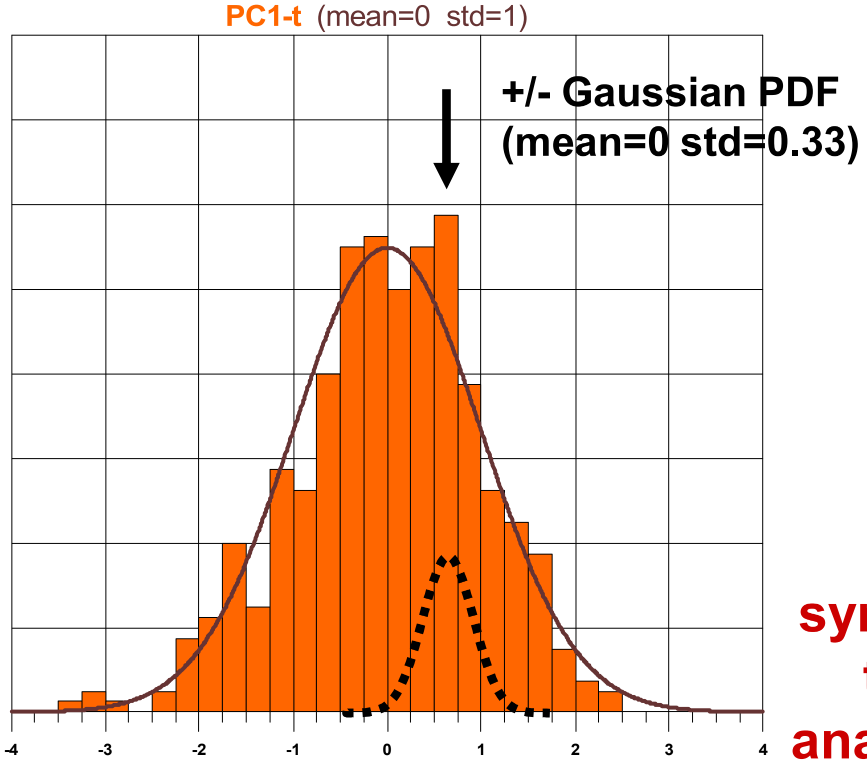
$V_{pot} \equiv Potential\ wind\ speed\ (ms^{-1})$,

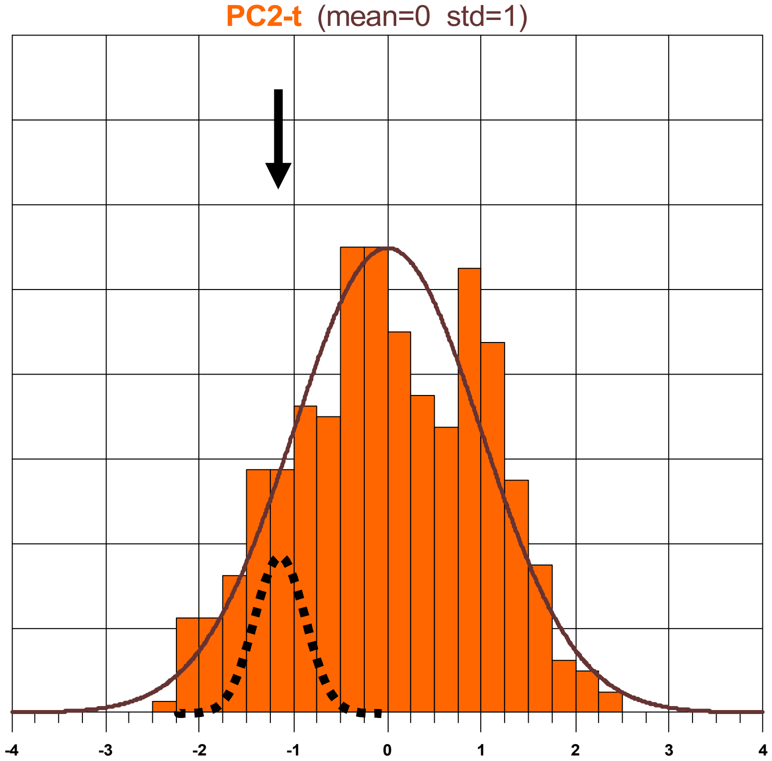
$V_{shear} \equiv \left|\mathbf{V}_{850} - \mathbf{V}_{250}\right|\ (ms^{-1})$.



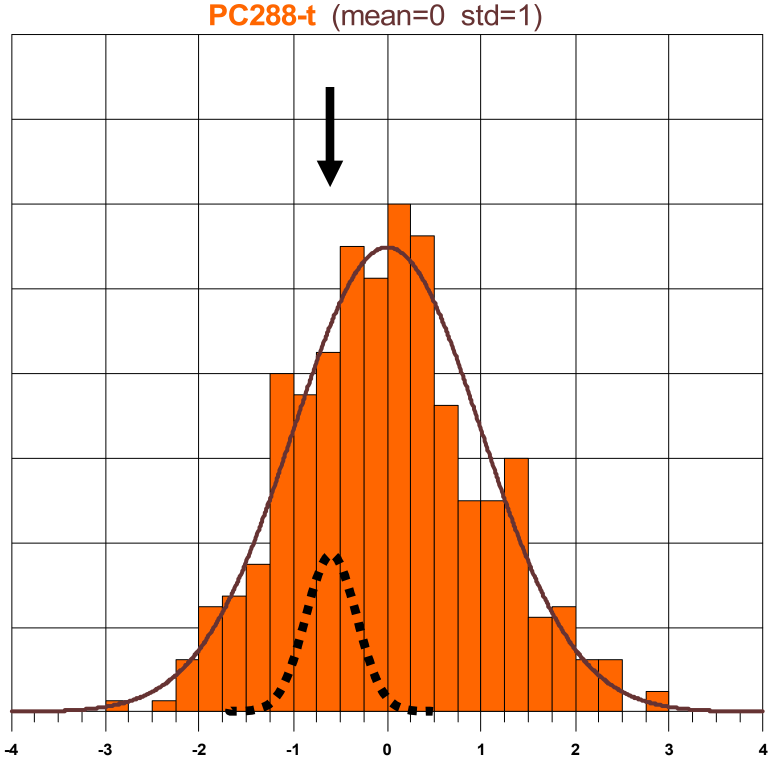


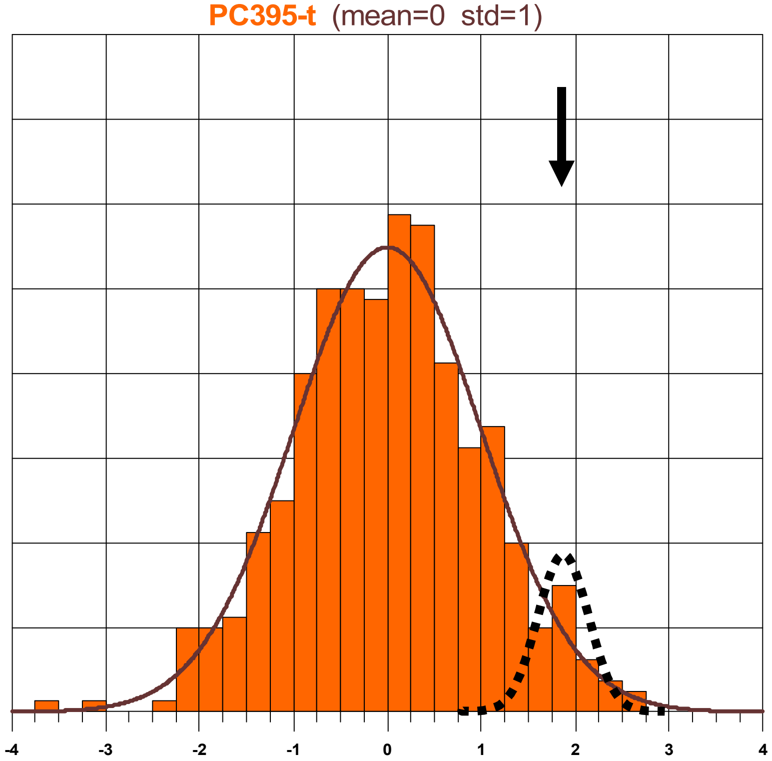
• Necessary but no sufficient ingredient …





Production of synoptic evolutions that behave as analogs of locations actually visited in the climate phase space !!!





1 2 3 4 5 6 7 8 9 10 synthetic days

OPEN-SEA POINT + <u>MAX</u> OF GENIX > 10 units + ABS VOR > 10^{-4} s^{-1} ???

<u>YES</u>

Backward

(Max: 12 h)

Forward

(Max: 12 h over land)

<u>POTENTIAL</u>

<u>TRACK</u>

(Δt = 30 min)

$$\begin{cases} u_{track} = \alpha\, \underline{u}_{850} + (1 - \alpha)\, \underline{u}_{250} \\ v_{track} = \alpha\, \underline{v}_{850} + (1 - \alpha)\, \underline{v}_{250} \end{cases}$$

$\underline{AVG}_{time\text{-}space}$

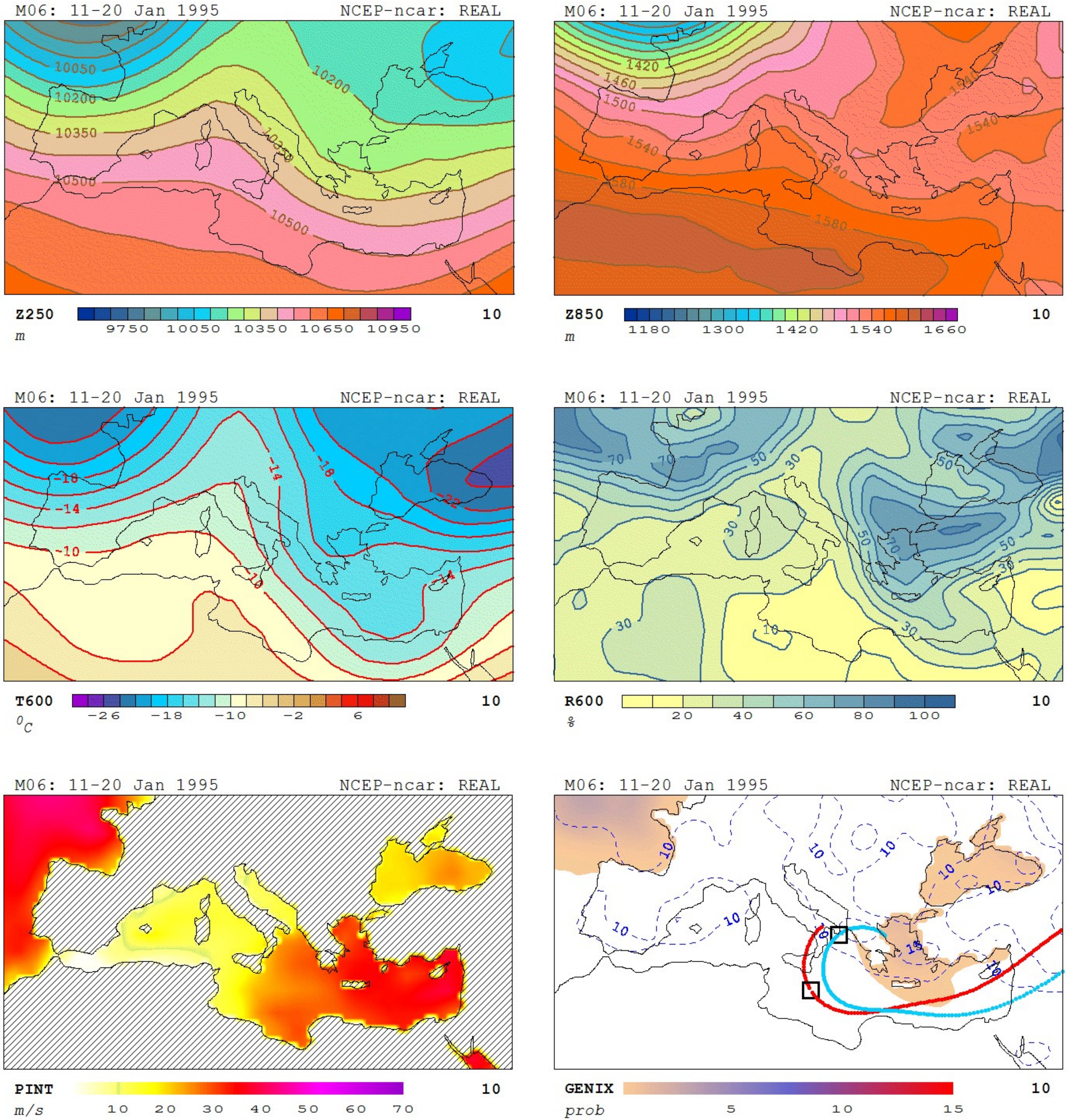
$\alpha = 0.8$

ILLUSTRATIVE EXAMPLE

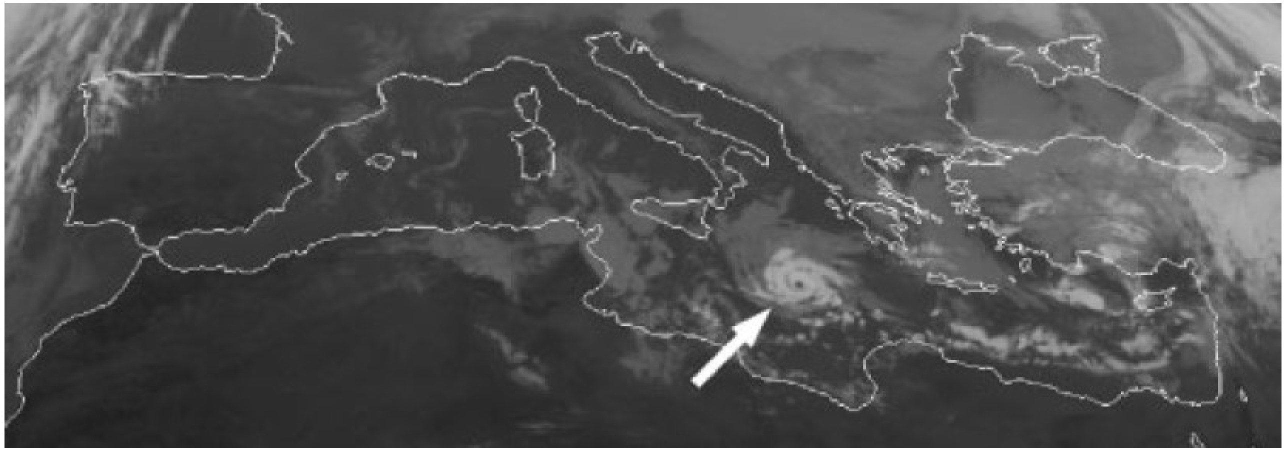
"LYBIAN" MEDICANE

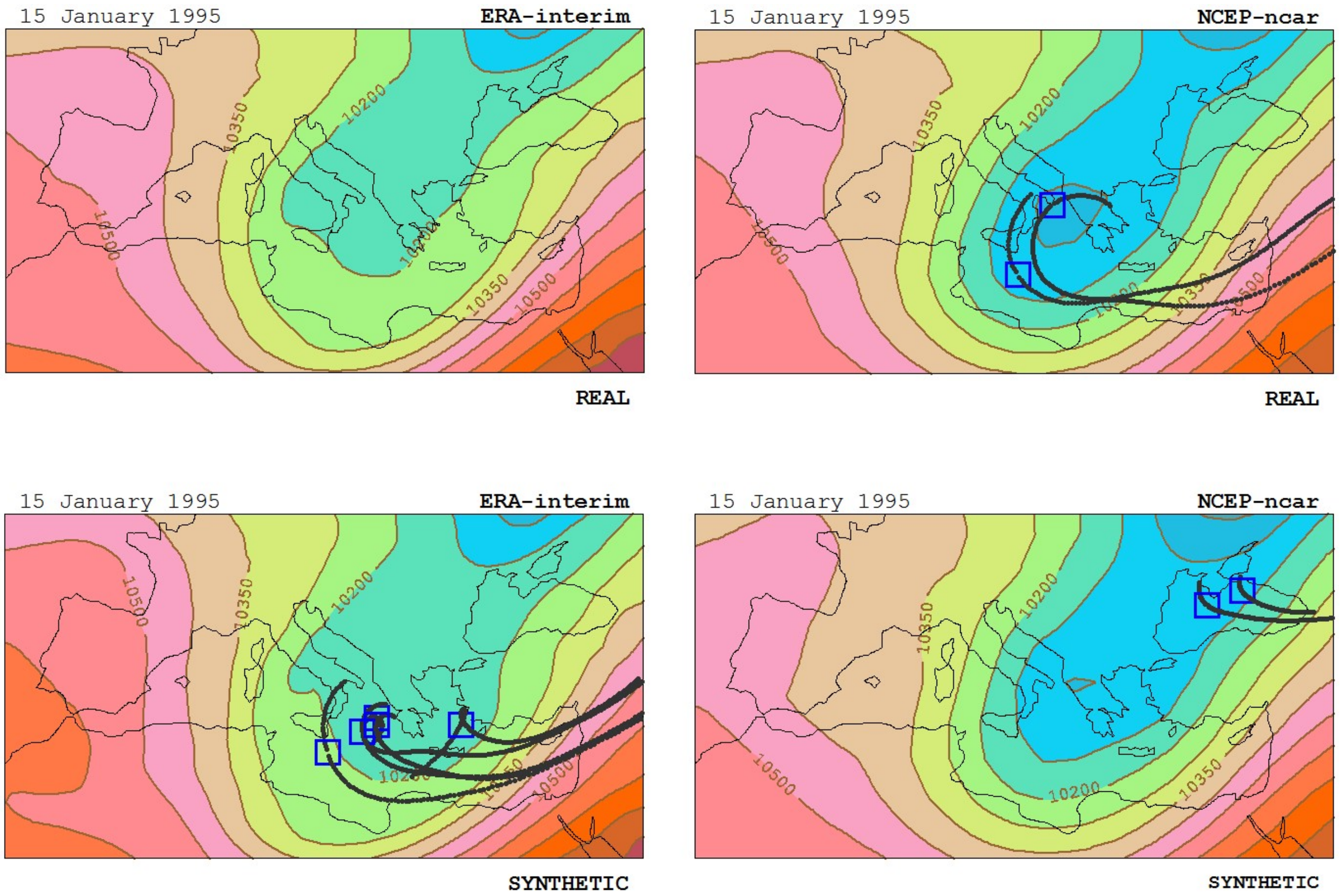
Central Mediterranean, 15-16 January 1995

TRACKING method



SYNTHETIC analogues





RESULTS

REANALYSIS 1

ERA-interim

20349 tracks
7918 survivors

200 storms/century

REANALYSIS 2

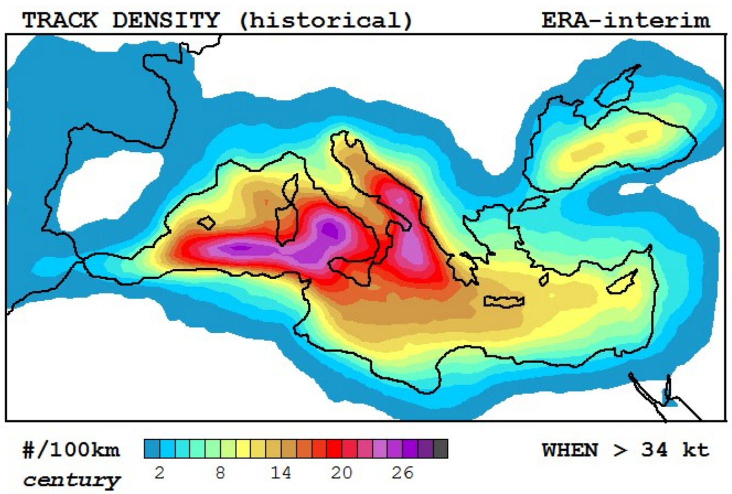
NCEP-ncar

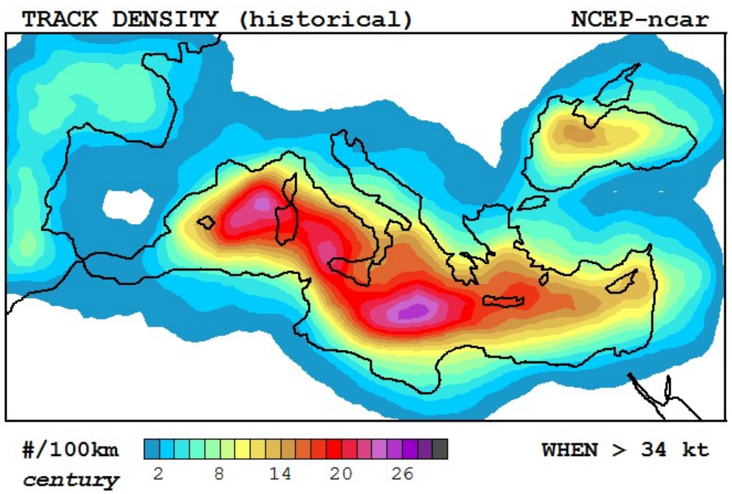
20276 tracks
6379 survivors

200 storms/century

HISTORICAL scenario

200 storms (per century)





GCM-01	GCM-02	GCM-06	GCM-07	GCM-11	GCM-12
ACCESS1.0	***ACCESS1.3***	***CanESM2***	***CCSM4***	***CNRM-CM5***	***CSIRO-Mk3.6.0***
20325 tracks	20086 tracks	20097 tracks	20405 tracks	20329 tracks	20048 tracks
7188 survivors	7281 survivors	5268 survivors	7012 survivors	6535 survivors	6034 survivors
200 storms/century	200 storms/century	200 storms/century	200 storms/century	200 storms/century	200 storms/century

GCM-03	GCM-04	GCM-08	GCM-09	GCM-13	GCM-14
BCC-CSM1.1	***BCC-CSM1.1(m)***	***CMCC-CESM***	***CMCC-CM***	***EC-EARTH***	***FGOALS-g2***
20083 tracks	20142 tracks	20106 tracks	20085 tracks	20180 tracks	20481 tracks
3045 survivors	5167 survivors	4733 survivors	6368 survivors	7793 survivors	1925 survivors
200 storms/century	200 storms/century	200 storms/century	200 storms/century	200 storms/century	200 storms/century

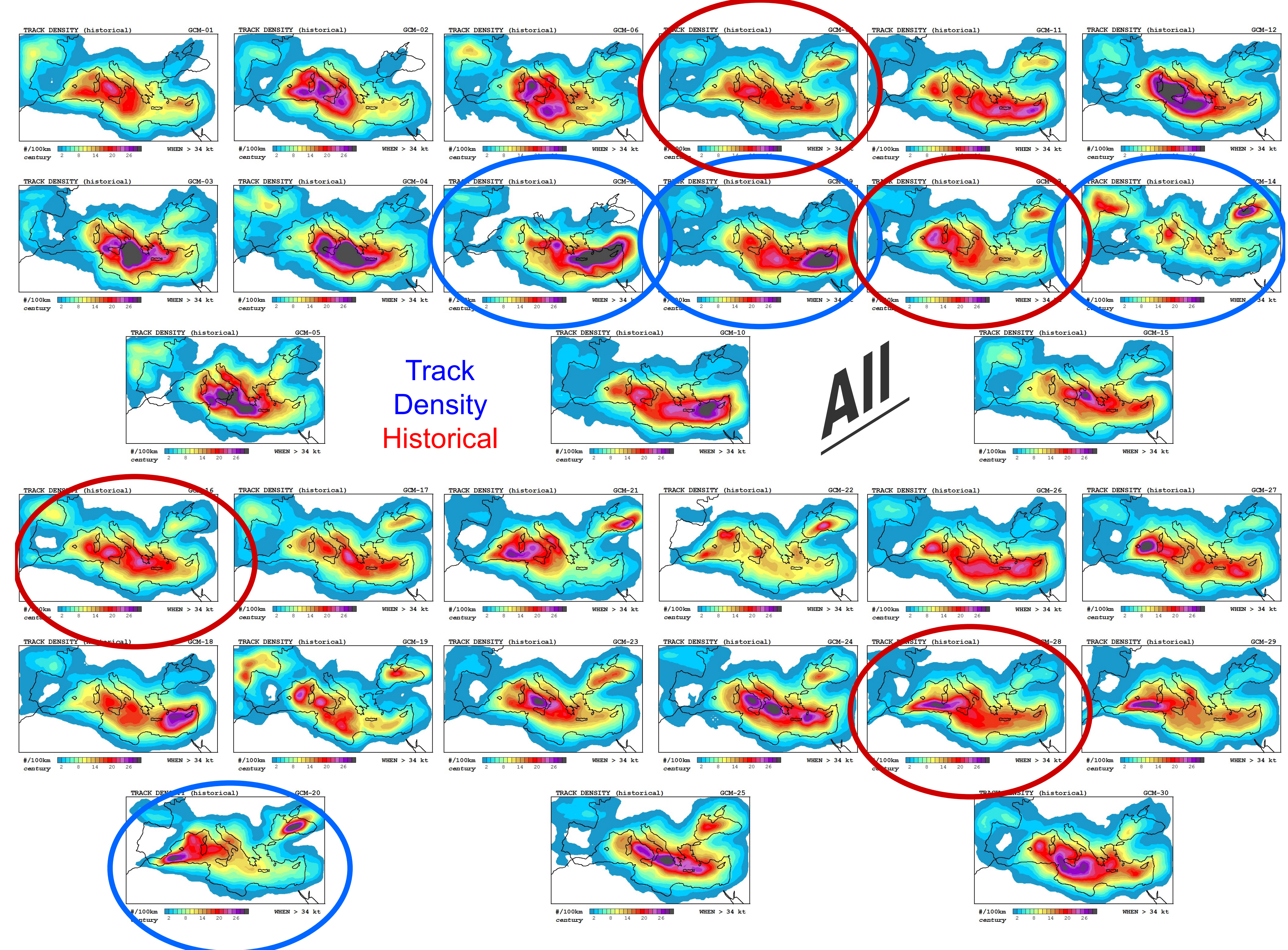
GCM-05		GCM-10		GCM-15
BNU-ESM	***HISTORICAL scenario***	***CMCC-CMS***	**ALL**	***GFDL-CM3***
20071 tracks		20119 tracks		20475 tracks
2946 survivors	**200 storms** (per century)	5738 survivors		5307 survivors
200 storms/century		200 storms/century		200 storms/century

GCM-16	GCM-17	GCM-21	GCM-22	GCM-26	GCM-27
GFDL-ESM2G	***GFDL-ESM2M***	***IPSL-CM5A-MR***	***IPSL-CM5B-LR***	***MPI-ESM-LR***	***MPI-ESM-MR***
20444 tracks	20374 tracks	20178 tracks	20592 tracks	20082 tracks	20745 tracks
5309 survivors	5596 survivors	4919 survivors	5681 survivors	6015 survivors	5678 survivors
200 storms/century	200 storms/century	200 storms/century	200 storms/century	200 storms/century	200 storms/century

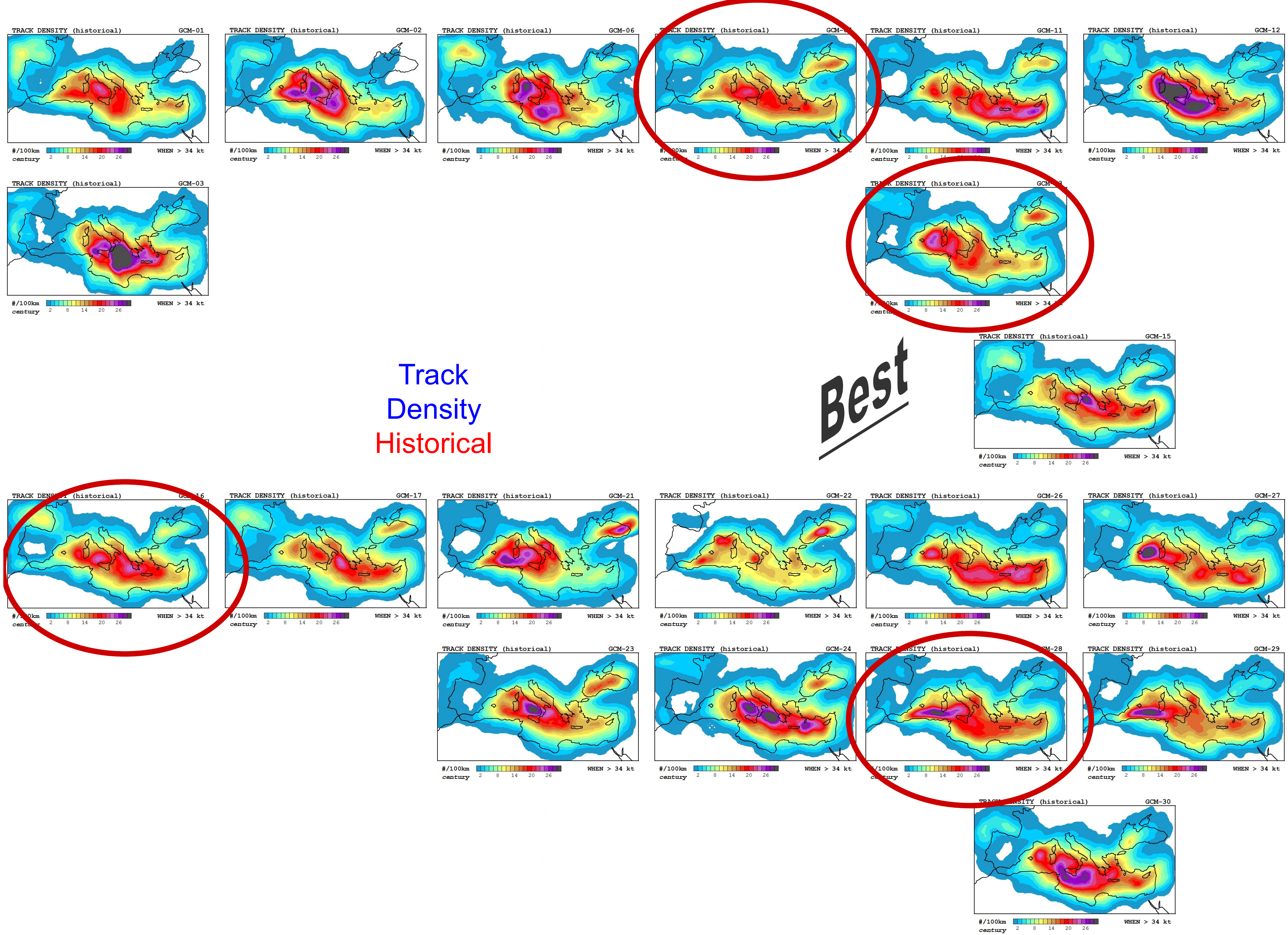
GCM-18	GCM-19	GCM-23	GCM-24	GCM-28	GCM-29
HadGEM2-CC	***INM-CM4***	***MIROC5***	***MIROC-ESM***	***MRI-CGCM3***	***MRI-ESM1***
20392 tracks	20018 tracks	20651 tracks	20268 tracks	20541 tracks	21203 tracks
7860 survivors	5047 survivors	6651 survivors	5709 survivors	5647 survivors	5898 survivors
200 storms/century	200 storms/century	200 storms/century	200 storms/century	200 storms/century	200 storms/century

GCM-20	GCM-25	GCM-30
IPSL-CM5A-LR	***MIROC-ESM-CHEM***	***NorESM1-M***
20176 tracks	20026 tracks	20022 tracks
5064 survivors	5517 survivors	6558 survivors
200 storms/century	200 storms/century	200 storms/century

GCM-01 *ACCESS1.0* 22539 tracks 7521 survivors 209.27 storms/century	GCM-02 *ACCESS1.3* 28304 tracks 8335 survivors 228.95 storms/century	GCM-06 *CanESM2* 14750 tracks 3843 survivors 145.90 storms/century	GCM-07 *CCSM4* 20560 tracks 6236 survivors 177.87 storms/century	GCM-11 *CNRM-CM5* 30505 tracks 8689 survivors 265.92 storms/century	GCM-12 *CSIRO-Mk3.6.0* 12085 tracks 2382 survivors 78.95 storms/century
GCM-03 *BCC-CSM1.1* 20439 tracks 2932 survivors 192.58 storms/century	GCM-04 *BCC-CSM1.1(m)* 13761 tracks 3523 survivors 136.37 storms/century	GCM-08 *CMCC-CESM* 17277 tracks 3772 survivors 159.39 storms/century	GCM-09 *CMCC-CM* 22778 tracks 7300 survivors 229.27 storms/century	GCM-13 *EC-EARTH* 32781 tracks 12359 survivors 317.18 storms/century	GCM-14 *FGOALS-g2* 29286 tracks 2730 survivors 283.64 storms/century
GCM-05 *BNU-ESM* 27750 tracks 3820 survivors 259.34 storms/century	***RCP85 scenario*** **198.52 storms (per century)**	GCM-10 *CMCC-CMS* 20675 tracks 6194 survivors 215.89 storms/century	**ALL**	GCM-15 *GFDL-CM3* 17779 tracks 4171 survivors 157.19 storms/century	
GCM-16 *GFDL-ESM2G* 20348 tracks 4686 survivors 176.53 storms/century	GCM-17 *GFDL-ESM2M* 16884 tracks 3996 survivors 142.82 storms/century	GCM-21 *IPSL-CM5A-MR* 14172 tracks 2382 survivors 96.85 storms/century	GCM-22 *IPSL-CM5B-LR* 23922 tracks 6328 survivors 222.78 storms/century	GCM-26 *MPI-ESM-LR* 19684 tracks 6708 survivors 223.04 storms/century	GCM-27 *MPI-ESM-MR* 21590 tracks 6969 survivors 245.47 storms/century
GCM-18 *HadGEM2-CC* 24510 tracks 7503 survivors 190.92 storms/century	GCM-19 *INM-CM4* 12250 tracks 2844 survivors 112.70 storms/century	GCM-23 *MIROC5* 29654 tracks 9216 survivors 277.13 storms/century	GCM-24 *MIROC-ESM* 27239 tracks 5499 survivors 192.64 storms/century	GCM-28 *MRI-CGCM3* 22758 tracks 5993 survivors 212.25 storms/century	GCM-29 *MRI-ESM1* 23950 tracks 6432 survivors 218.11 storms/century
GCM-20 *IPSL-CM5A-LR* 23722 tracks 5438 survivors 214.77 storms/century	**15 models** ▼▼▼	GCM-25 *MIROC-ESM-CHEM* 26010 tracks 5283 survivors 191.52 storms/century	**15 models** ▲▲▲	GCM-30 *NorESM1-M* 22427 tracks 5914 survivors 180.36 storms/century	



TRACK DENSITY (historical)
GCM-01
GCM-02
GCM-06
GCM-11
GCM-12
GCM-03
GCM-04
GCM-14
GCM-05
GCM-10
GCM-15
GCM-16
GCM-17
GCM-21
GCM-22
GCM-26
GCM-27
GCM-18
GCM-19
GCM-23
GCM-24
GCM-28
GCM-29
GCM-20
GCM-25
GCM-30
#/100km century
2 8 14 20 26
WHEN > 34 kt
Track
Density
Historical
All


Track
Density
Historical
Best
TRACK DENSITY (historical) GCM-01
TRACK DENSITY (historical) GCM-02
TRACK DENSITY (historical) GCM-06
TRACK DENSITY (historical) GCM-11
TRACK DENSITY (historical) GCM-12
TRACK DENSITY (historical) GCM-03
TRACK DENSITY (historical) GCM-15
TRACK DENSITY (historical) GCM-17
TRACK DENSITY (historical) GCM-21
TRACK DENSITY (historical) GCM-22
TRACK DENSITY (historical) GCM-26
TRACK DENSITY (historical) GCM-27
TRACK DENSITY (historical) GCM-23
TRACK DENSITY (historical) GCM-24
TRACK DENSITY (historical) GCM-29
GCM-30
#/100km century
2 8 14 20 26
WHEN > 34 kt

GCM-01
ACCESS1.0
22539 tracks
7521 survivors
209.27 storms/century

GCM-02
ACCESS1.3
28304 tracks
8335 survivors
228.95 storms/century

GCM-06
CanESM2
14750 tracks
3843 survivors
145.90 storms/century

GCM-07
CCSM4
20560 tracks
6236 survivors
177.87 storms/century

GCM-11
CNRM-CM5
30505 tracks
8689 survivors
265.92 storms/century

GCM-12
CSIRO-Mk3.6.0
12085 tracks
2382 survivors
78.95 storms/century

GCM-03
BCC-CSM1.1
20439 tracks
2932 survivors
192.58 storms/century

GCM-13
EC-EARTH
32781 tracks
12359 survivors
317.18 storms/century

HISTORICAL scenario

200 storms (per century)

- 1 %

RCP85 scenario

198.09 storms (per century)

BEST

GCM-15
GFDL-CM3
17779 tracks
4171 survivors
157.19 storms/century

GCM-16
GFDL-ESM2G
20348 tracks
4686 survivors
176.53 storms/century

GCM-17
GFDL-ESM2M
16884 tracks
3996 survivors
142.82 storms/century

GCM-21
IPSL-CM5A-MR
14172 tracks
2382 survivors
96.85 storms/century

GCM-22
IPSL-CM5B-LR
23922 tracks
6328 survivors
222.78 storms/century

GCM-26
MPI-ESM-LR
19684 tracks
6708 survivors
223.04 storms/century

GCM-27
MPI-ESM-MR
21590 tracks
6969 survivors
245.47 storms/century

GCM-23
MIROC5
29654 tracks
9216 survivors
277.13 storms/century

GCM-24
MIROC-ESM
27239 tracks
5499 survivors
192.64 storms/century

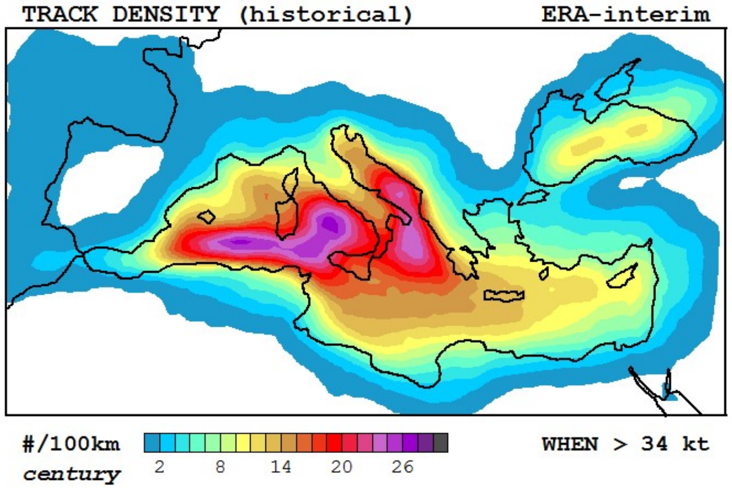
GCM-28
MRI-CGCM3
22758 tracks
5993 survivors
212.25 storms/century

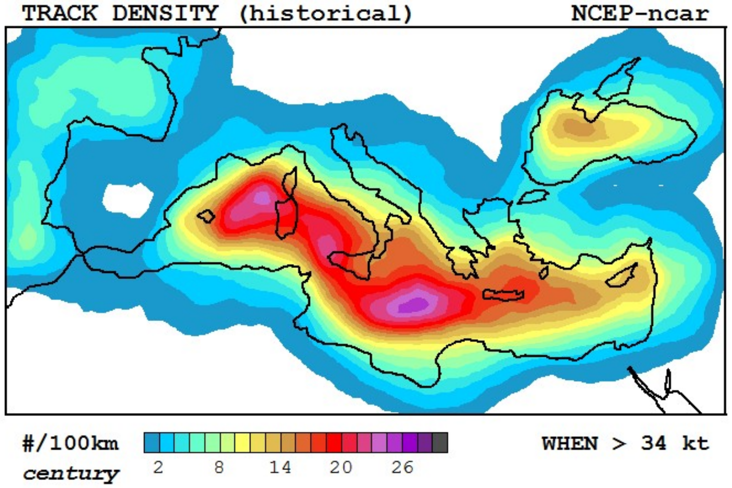
GCM-29
MRI-ESM1
23950 tracks
6432 survivors
218.11 storms/century

GCM-30
NorESM1-M
22427 tracks
5914 survivors
180.36 storms/century

10 models ▼▼▼

10 models ▲▲▲



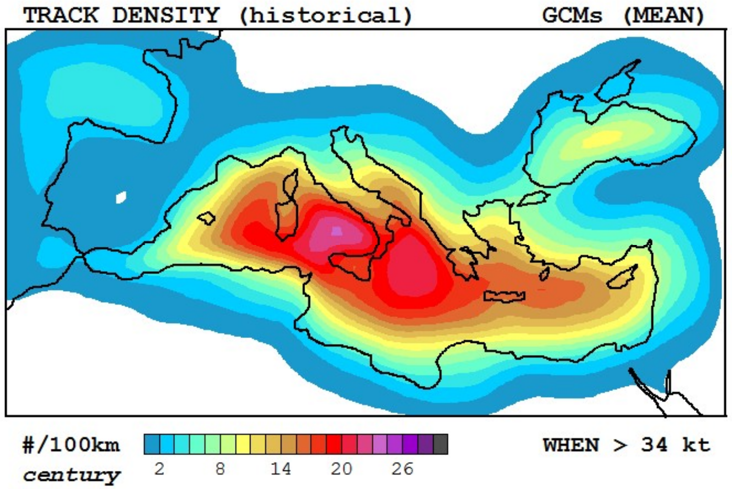


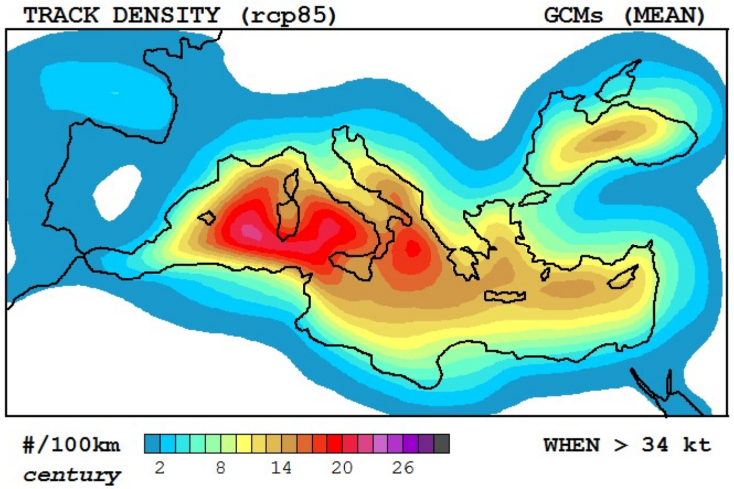
CORR

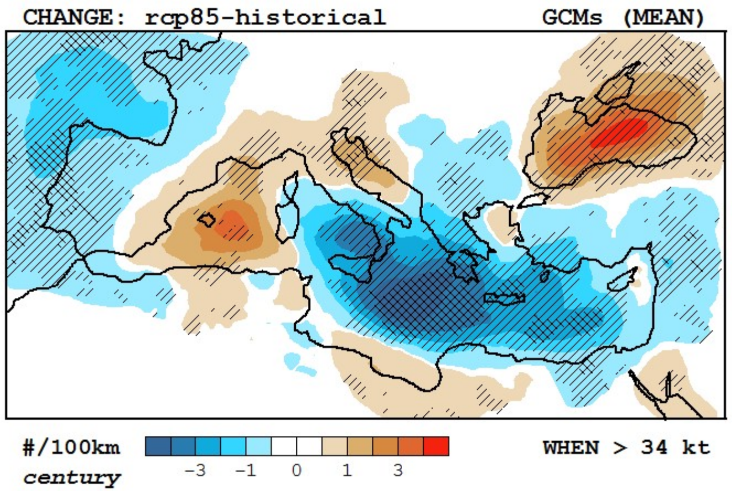
REAn01 = 0.948
REAn02 = 0.942
MEAN = **0.945**

RMSE

REAn01 = 1.907
REAn02 = 1.930
MEAN = **1.918**

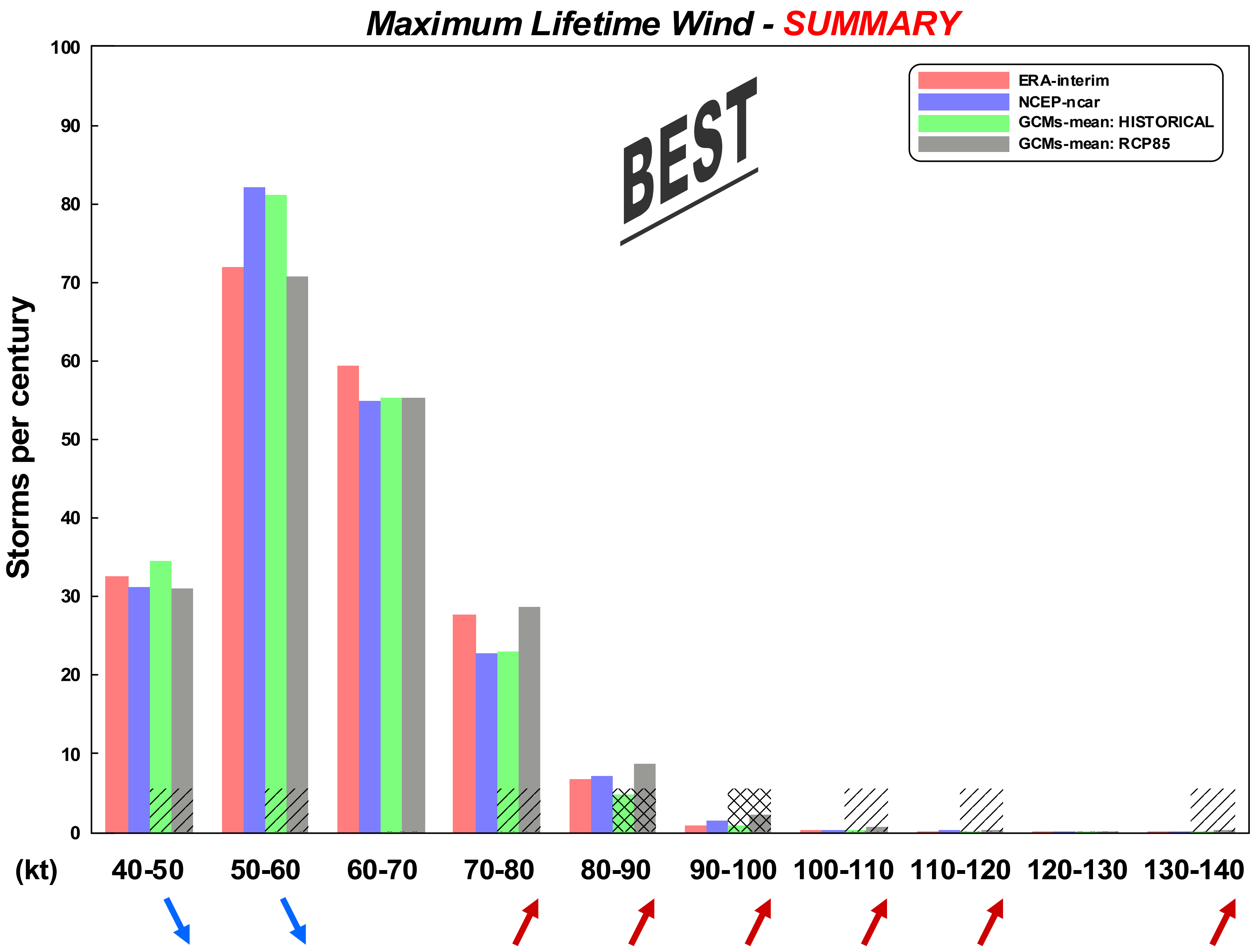


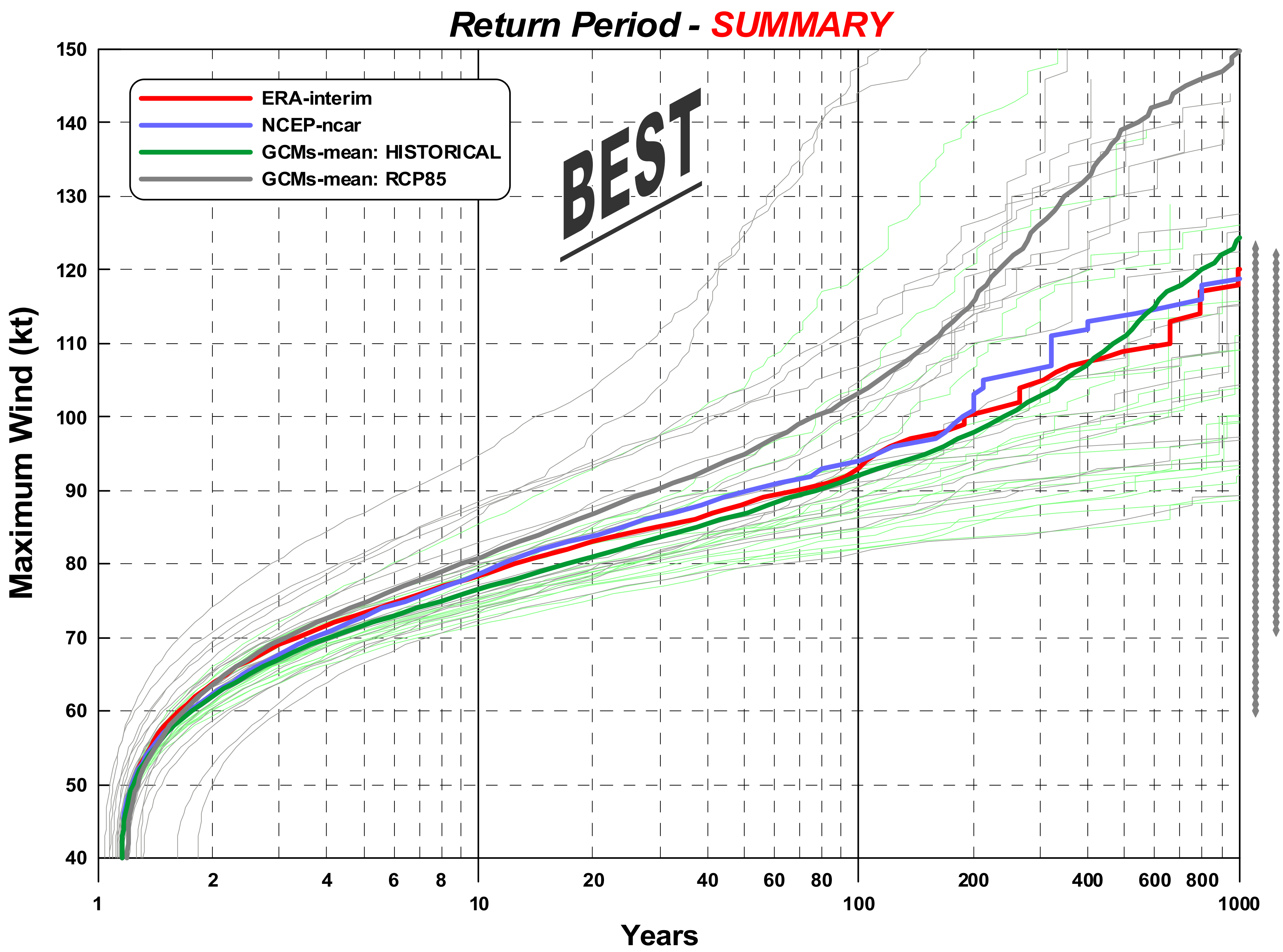




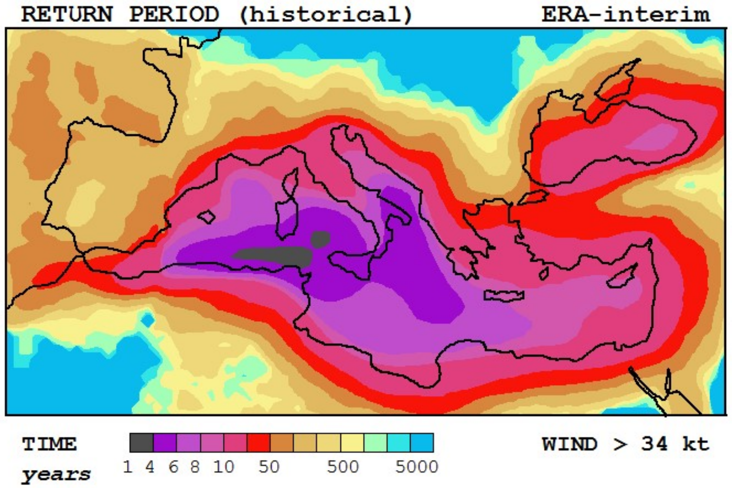
Track
Density
Summary

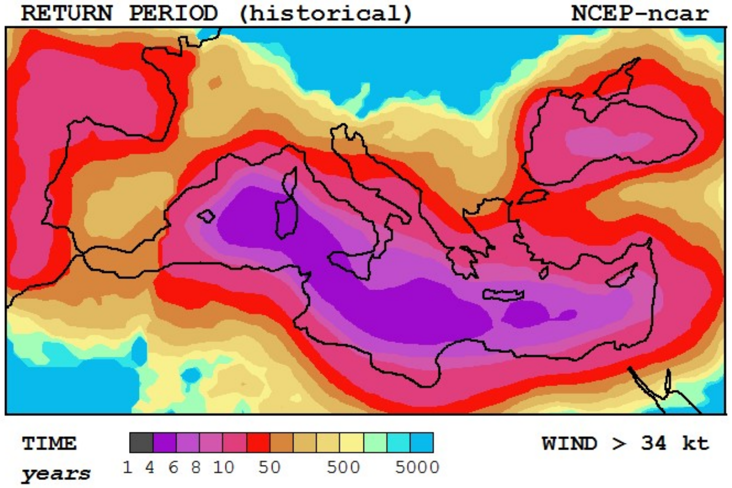
BEST


Maximum Lifetime Wind - SUMMARY
BEST
ERA-interim
NCEP-ncar
GCMs-mean: HISTORICAL
GCMs-mean: RCP85
Storms per century
0
10
20
30
40
50
60
70
80
90
100
(kt)
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140



Return Period - SUMMARY
ERA-interim
NCEP-ncar
GCMs-mean: HISTORICAL
GCMs-mean: RCP85
BEST
Maximum Wind (kt)
150
140
130
120
110
100
90
80
70
60
50
40
1
2
4
6
8
10
20
40
60
80
100
200
400
600
800
1000
Years



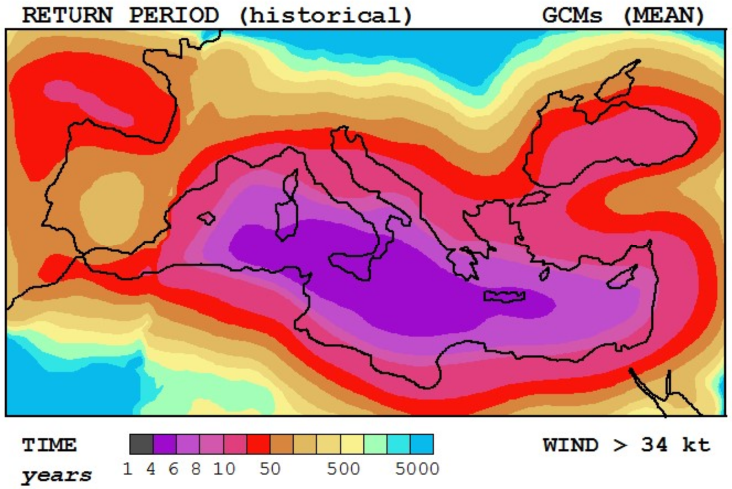


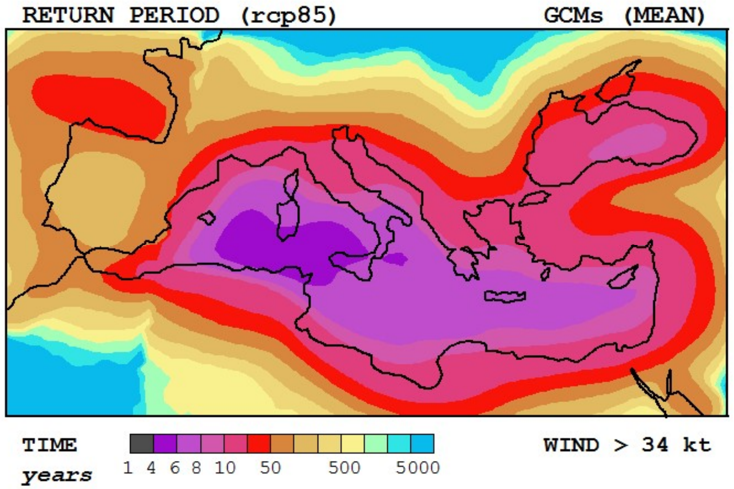
CORR

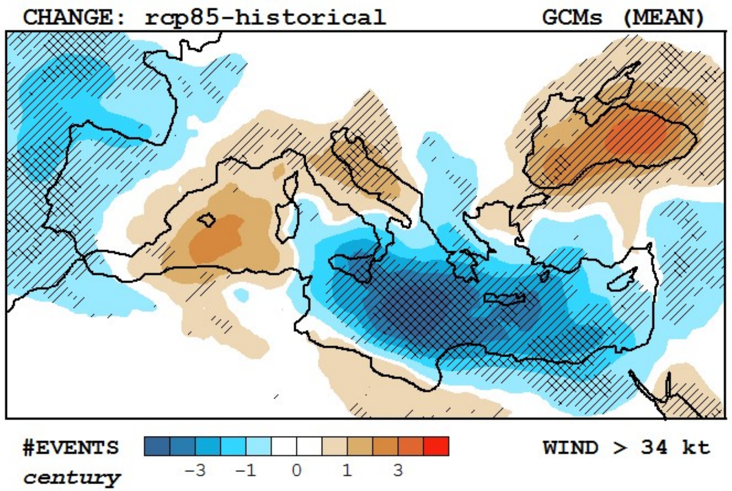
REAn01 = 0.768
REAn02 = 0.742
MEAN = **0.755**

RMSE

REAn01 = 2.157
REAn02 = 4.131
MEAN = **3.144**

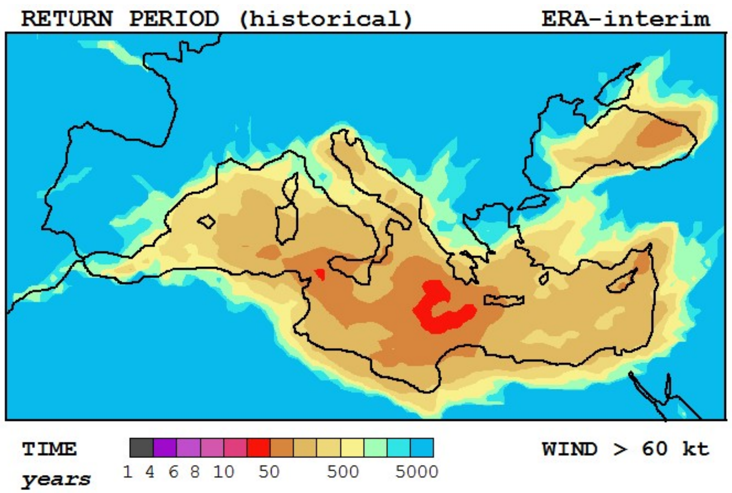


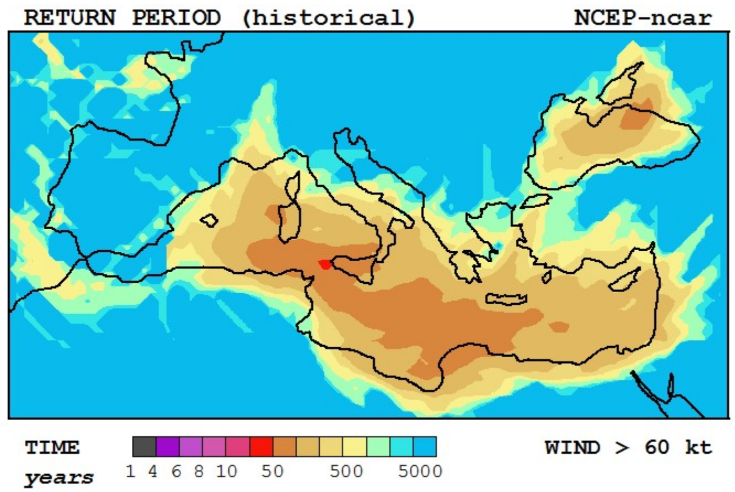




Return
Period 34 kt
Summary

BEST



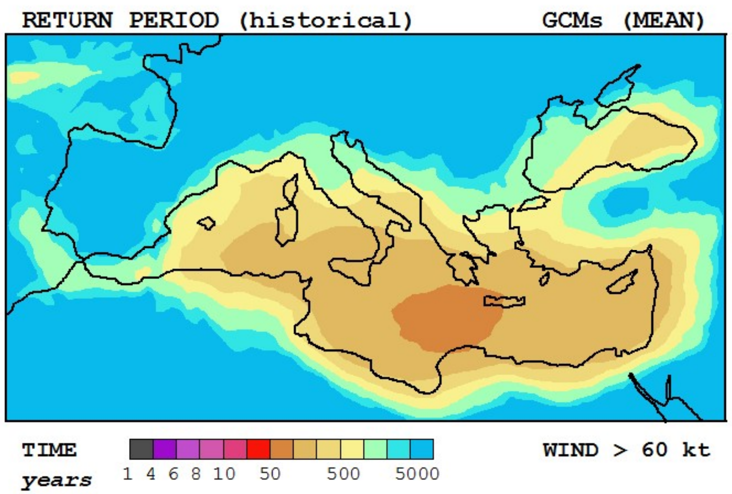


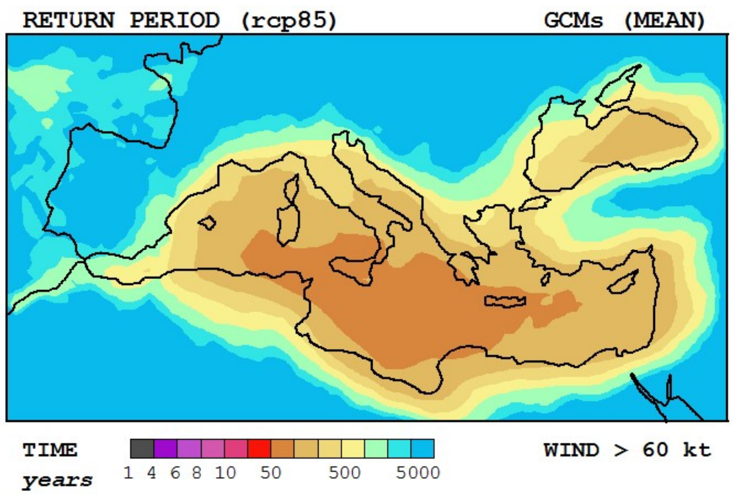
<u>CORR</u>

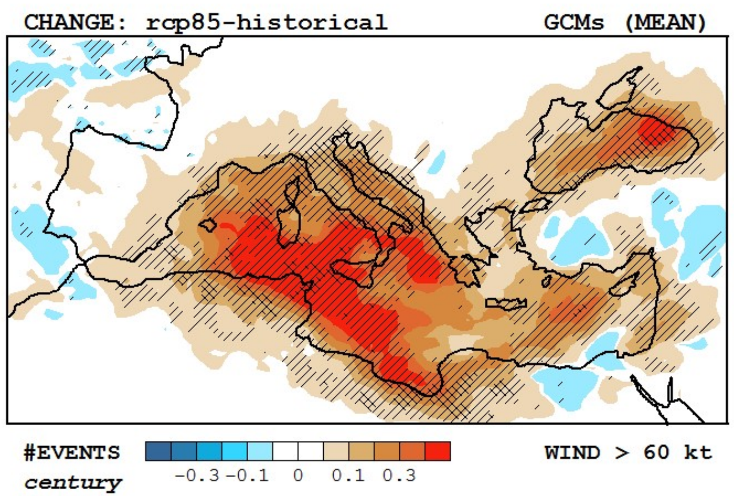
REAn01 = 0.604
REAn02 = 0.649
MEAN = **<u>0.626</u>**

<u>RMSE</u>

REAn01 = 4.972
REAn02 = 8.418
MEAN = **<u>6.695</u>**







Return
Period 60 kt
Summary

BEST

RAINFALL

TRAM SIMULATIONS

...see TRAM details in the QJRMS-ARTICLE

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RESEARCH ARTICLE

TRAM: A new non-hydrostatic fully compressible numerical model suited for all kinds of regional atmospheric predictions

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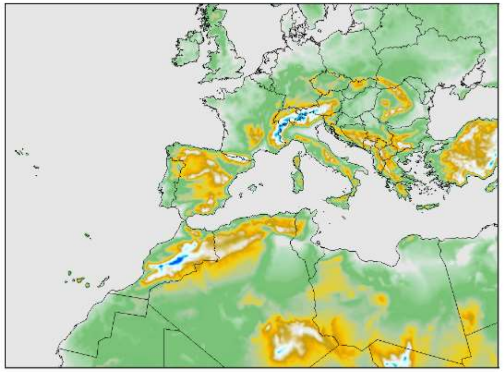
Abstract

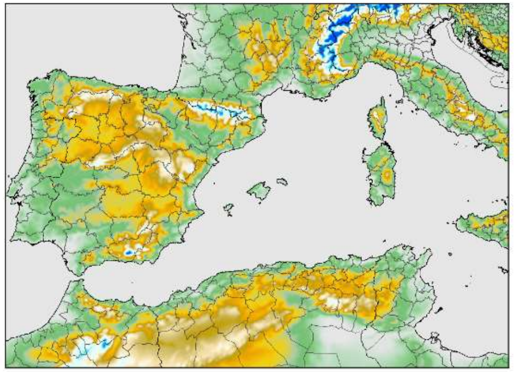
A new limited-area numerical model (TRAM, for Triangle-based Regional Atmospheric Model) has been built using a non-hydrostatic and fully compressible version of the Navier–Stokes equations. Advection terms are solved using a Reconstruct–Evolve–Average (REA) strategy over the computational cells. These cells consist of equilateral triangles in the horizontal. The classical *z*-coordinate is used in the vertical, allowing arbitrary stretching (e.g., higher resolution in the Planetary Boundary Layer, PBL). Proper treatment of terrain slopes in the bottom boundary conditions allows for accurately representing the orographic forcing. To gain computational efficiency, time splitting is used to integrate fast and slow terms separately and acoustic modes in the vertical are solved implicitly. For real cases on the globe, the Lambert map projection

TRAM / MeteoUIB

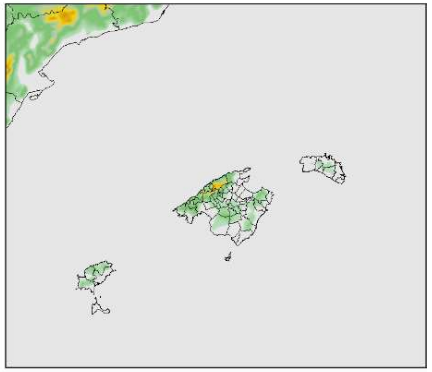
MR (17 km)



HR (6 km)



SR (2 km)

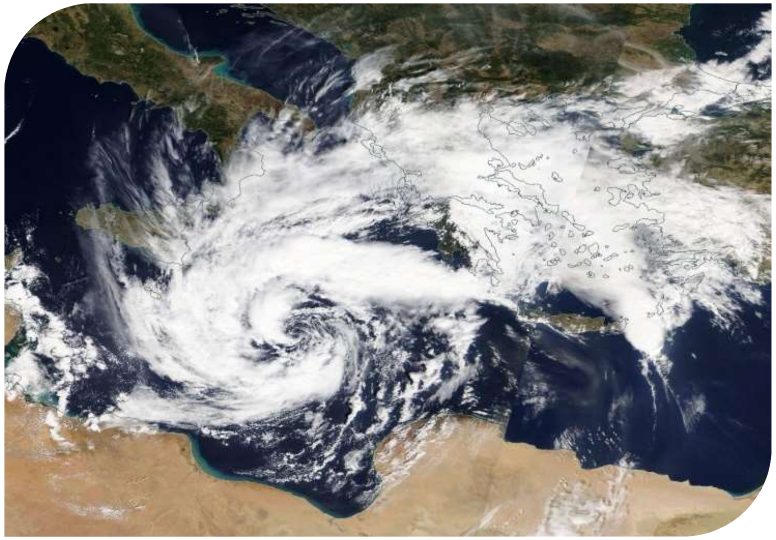


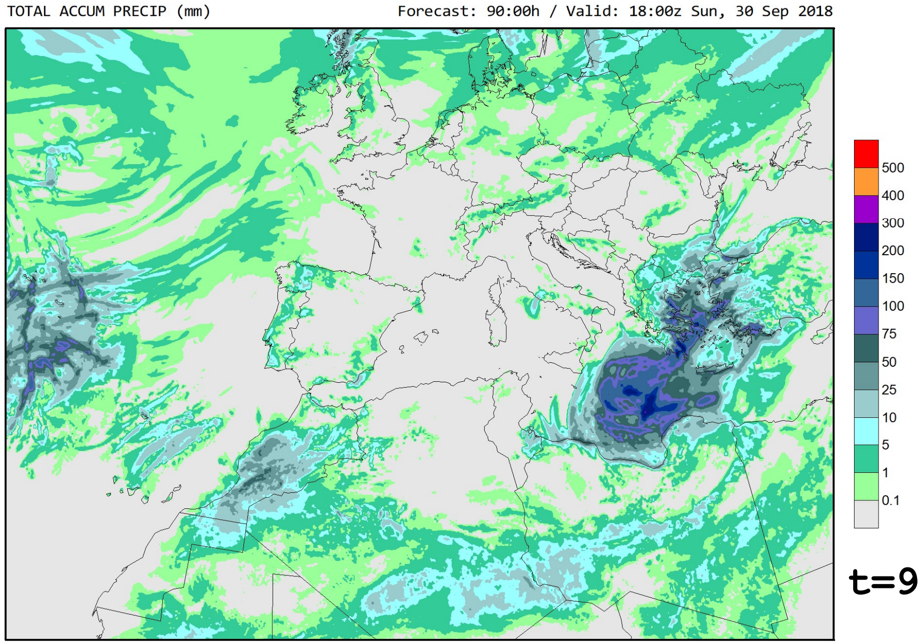
Grup de Meteorologia

Universitat de les Illes Balears

> "ZORBAS" Ionian Sea Medicane (IC: 00 UTC 27 Sept 2018)

(MR_double:dx=12.5km,dzm=250m,stretch=10,dt=25s,Nstep=6,90h)





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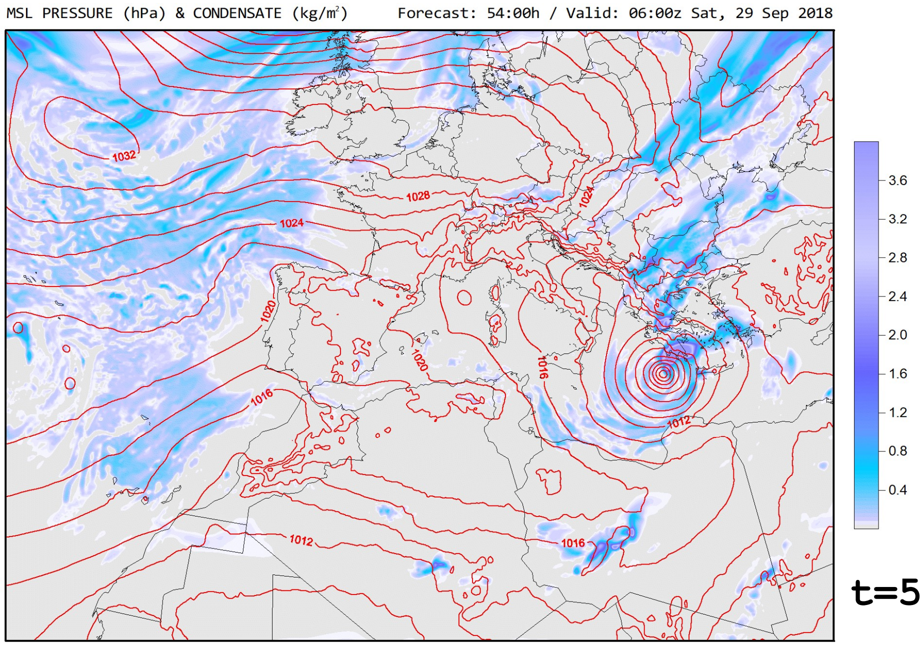

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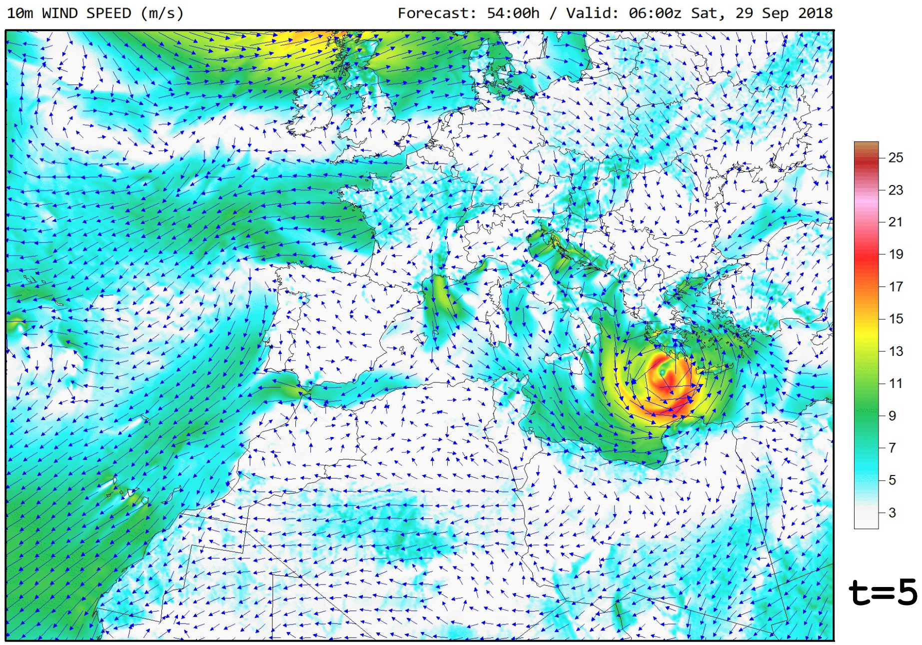

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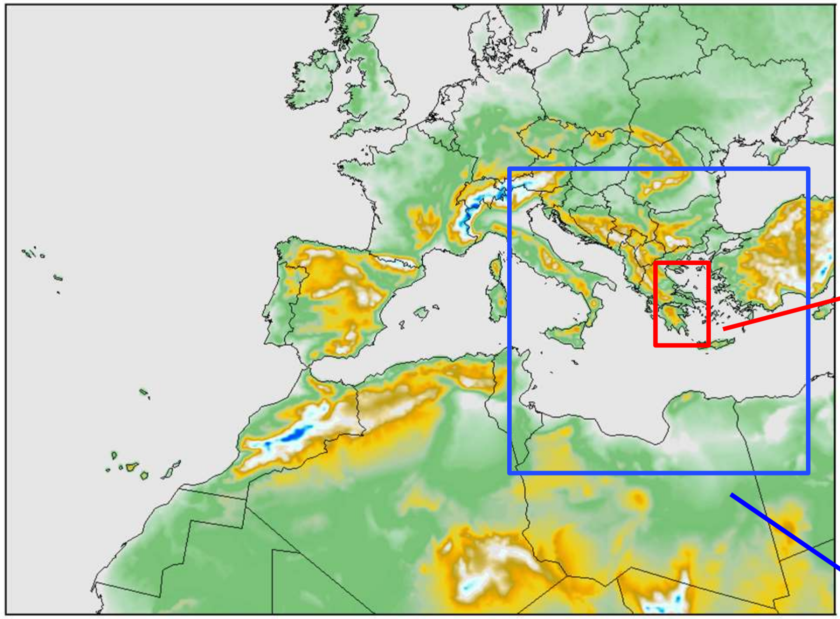
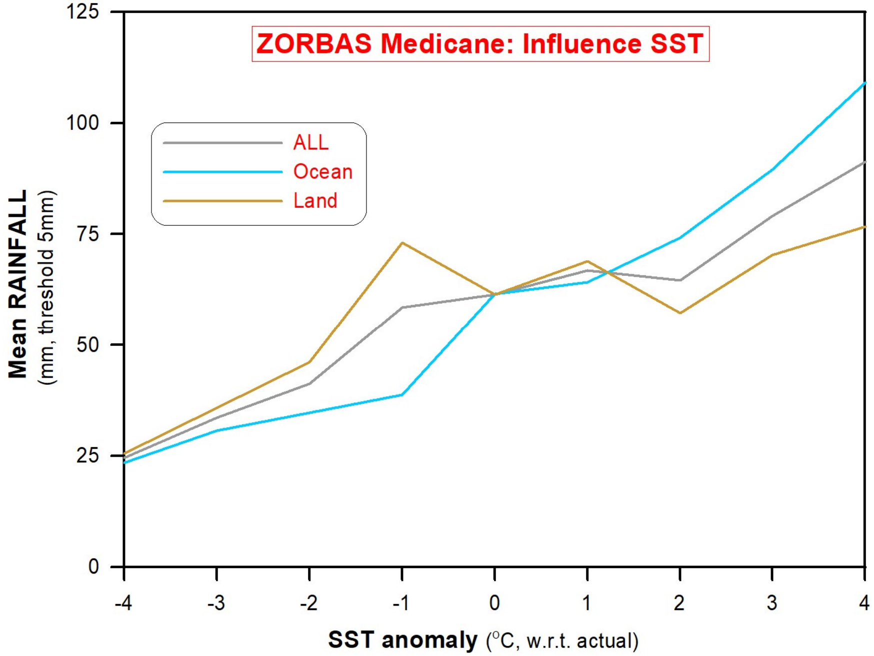
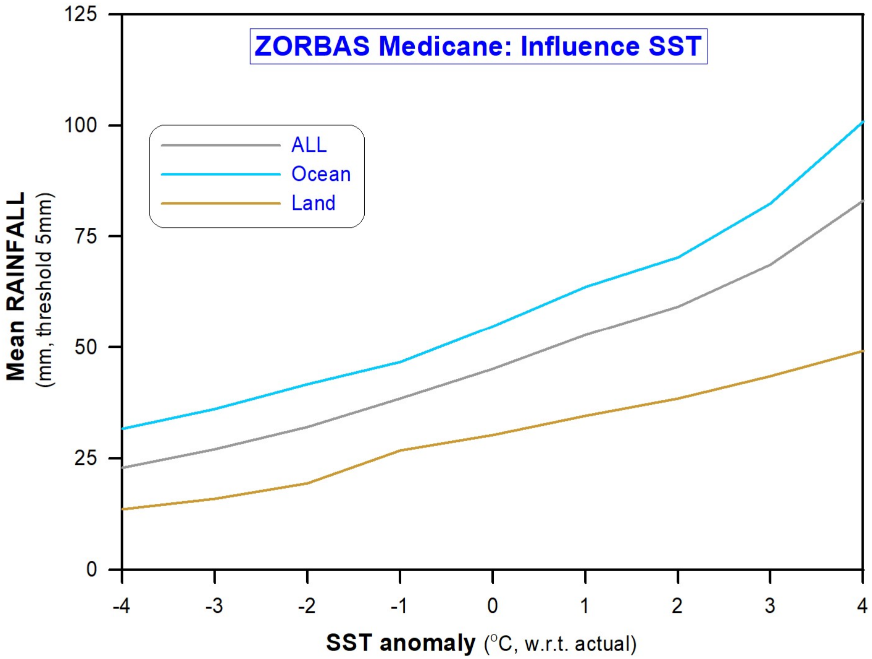
TRAM_physics_3D_operational + ERA5 Reanalyses

> "ZORBAS" Ionian Sea Medicane (IC: 00 UTC 27 Sept 2018) 90h-RUN



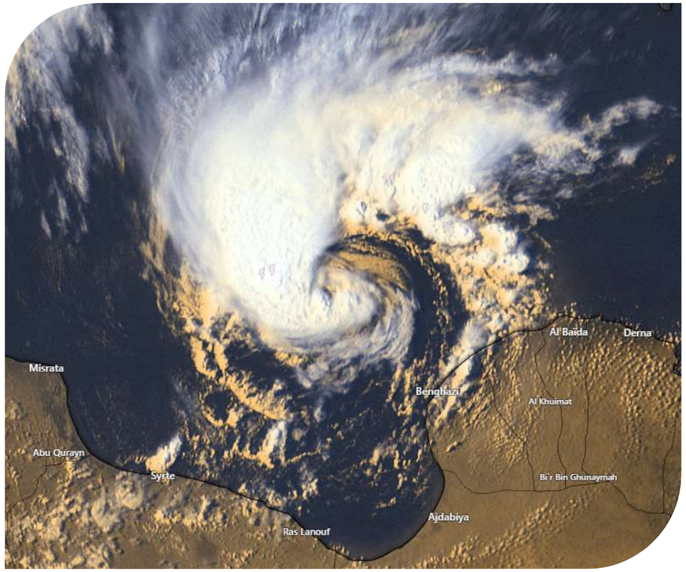




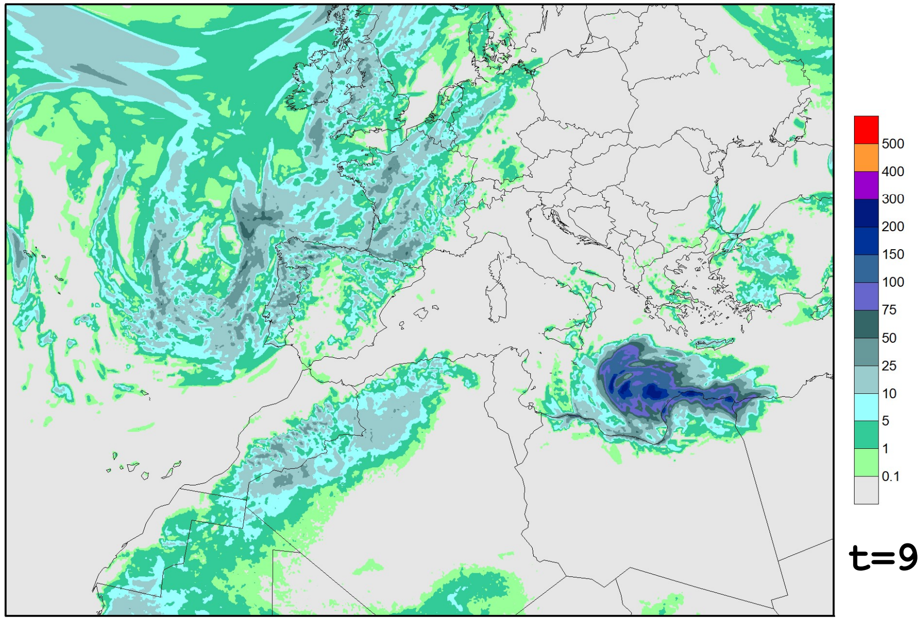
TRAM_physics_3D_operational + ERA5 Reanalyses

> "DANIEL" Lybian Sea Medicane (IC: 00 UTC 08 Sept 2023)

(MR_double:dx=12.5km,dzm=250m,stretch=10,dt=25s,Nstep=6,96h)

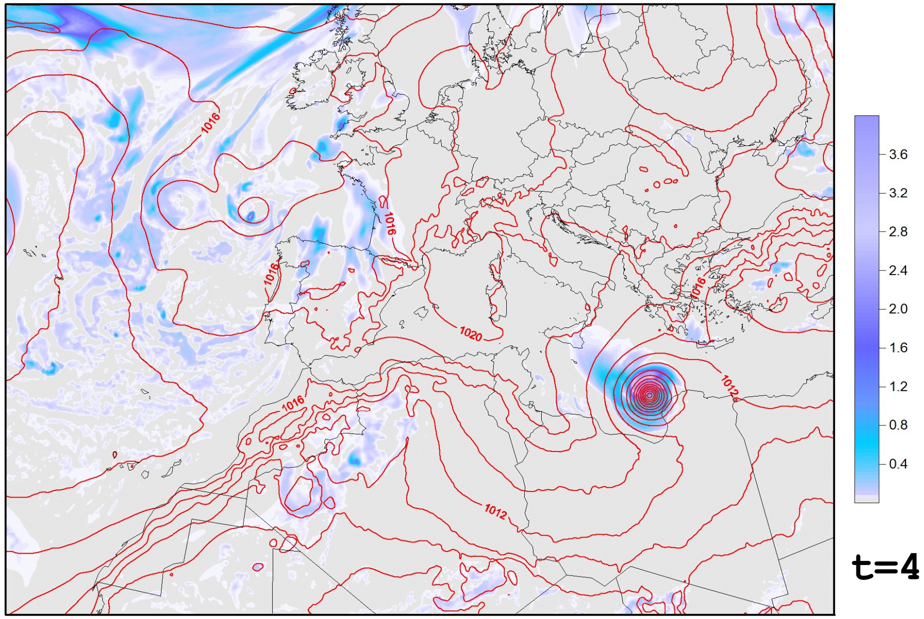


TOTAL ACCUM PRECIP (mm) Forecast: 96:00h / Valid: 00:00z Tue, 12 Sep 2023



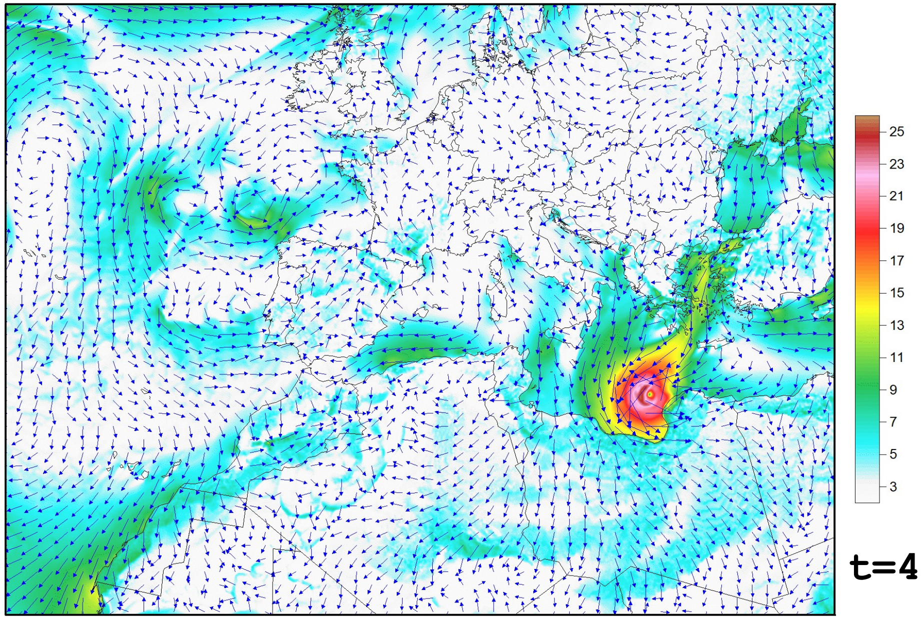
t=96h

MSL PRESSURE (hPa) & CONDENSATE (kg/m²) Forecast: 42:00h / Valid: 18:00z Sat, 09 Sep 2023



t=42h

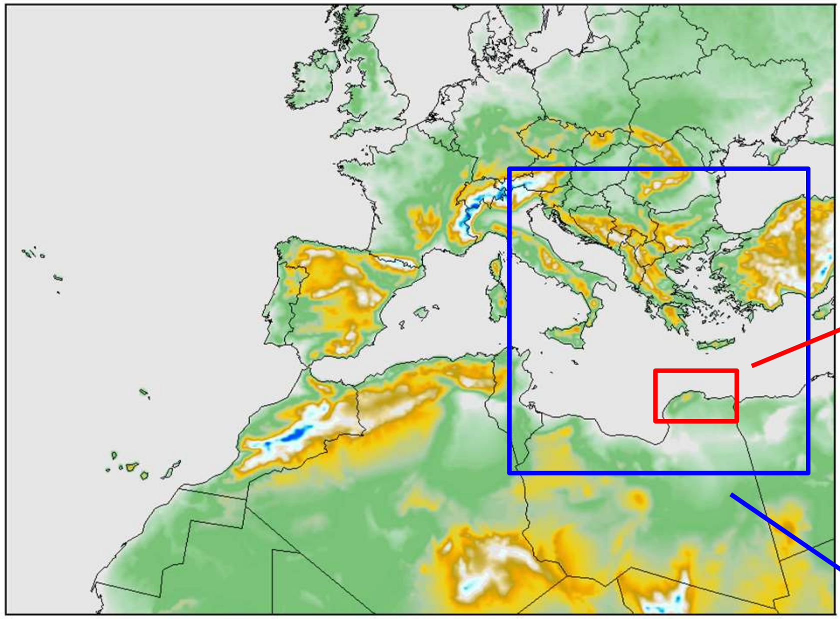
10m WIND SPEED (m/s) Forecast: 42:00h / Valid: 18:00z Sat, 09 Sep 2023

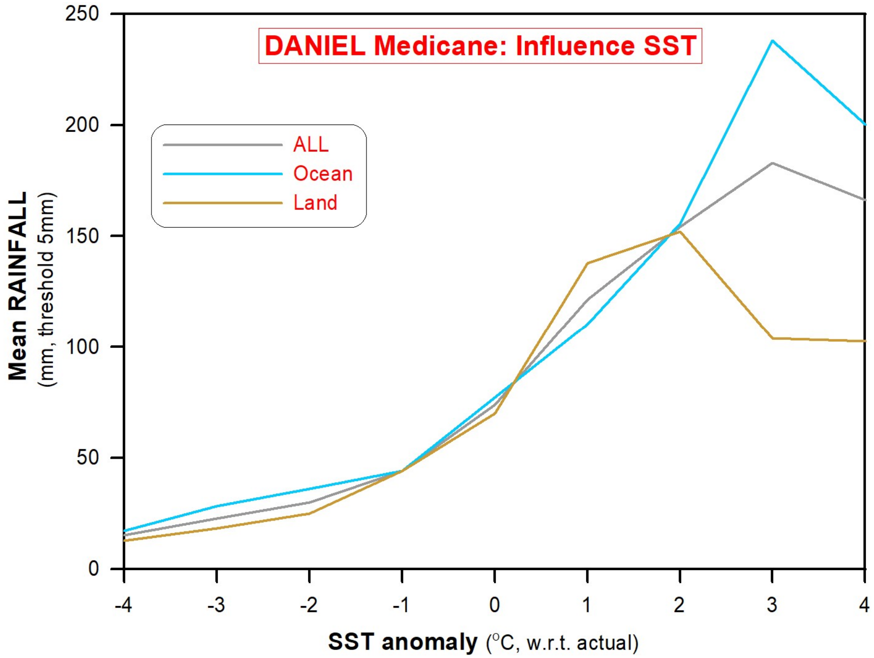


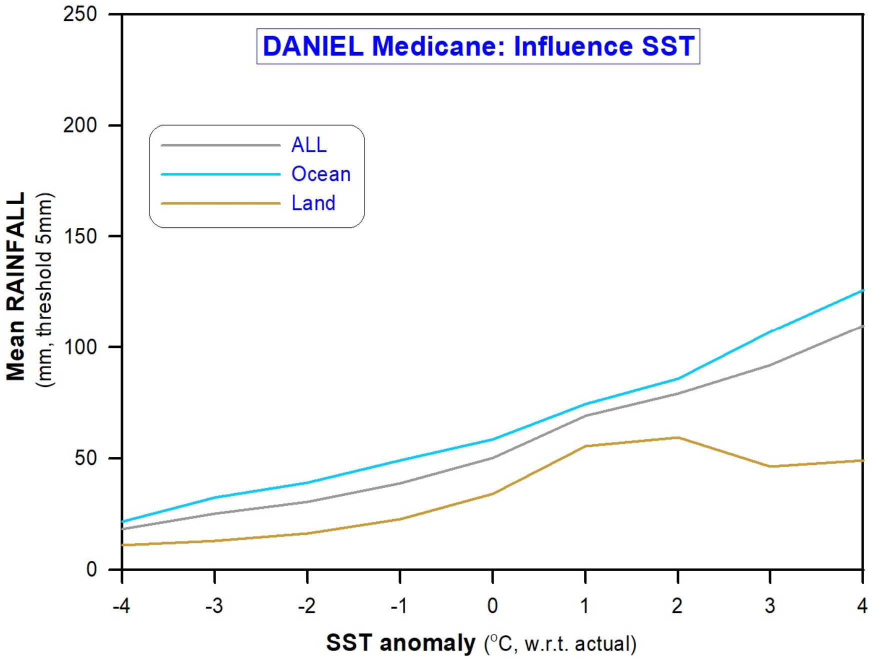
t=42h

TRAM_physics_3D_operational + ERA5 Reanalyses

> "DANIEL" Lybian Sea Medicane (IC: 00 UTC 08 Sept 2023) 96h-RUN





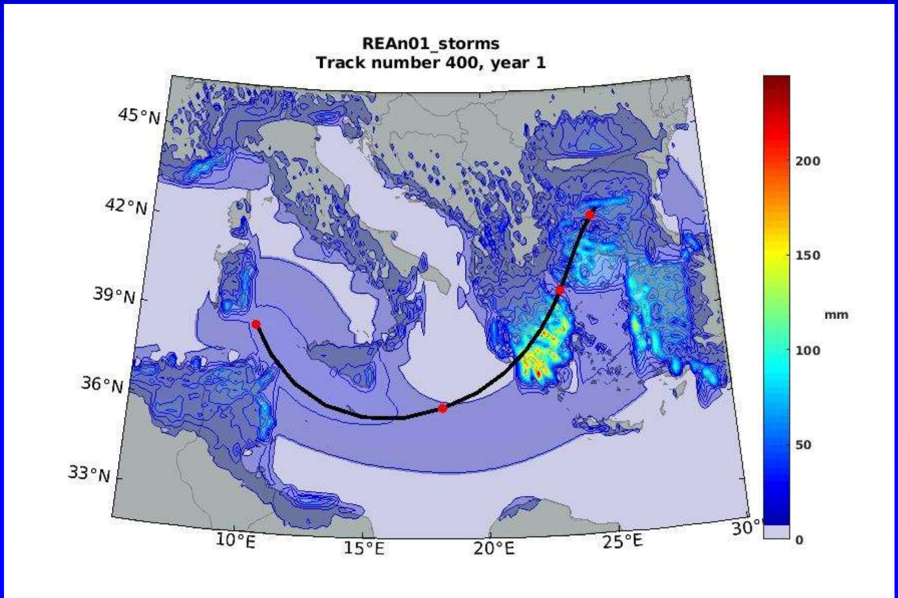


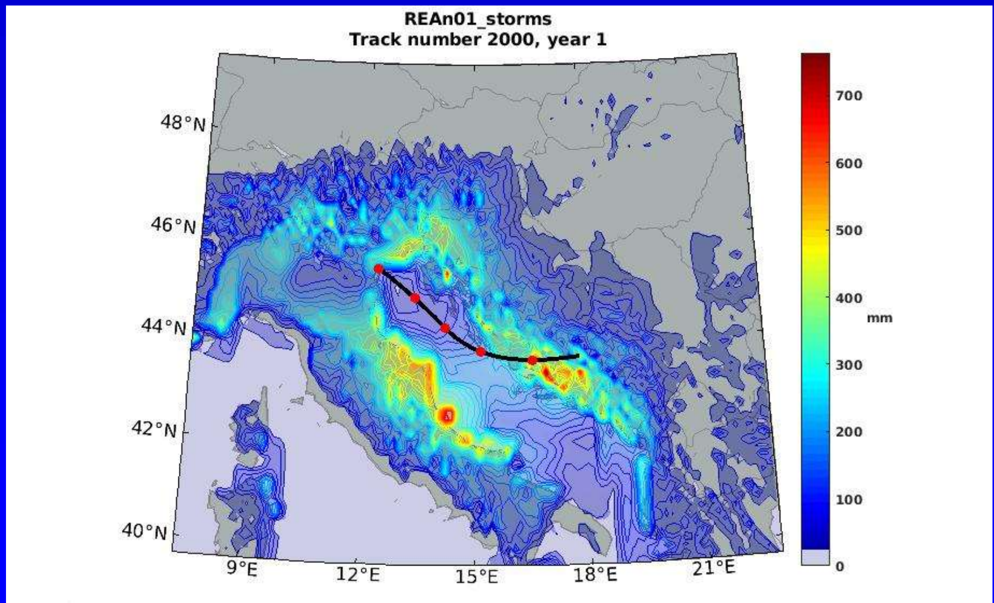
RAINFALL ALGORITHM: Feldmann & Emanuel et al. (JAMC, 2019)

• **Principle**: *Uses the net vertical velocity and the saturation specific humidity to calculate the vertical vapor flux, and this, multiplied by a precipitation efficiency, is assumed to equal the precipitation rate.*

• **CHIPS**: *w is a model variable, but poorly resolved outside the inner core and is not recorded. Additionally, topographical effects and asymmetries owing to interactions between the TC and environmental flow and surface friction are not accounted for in the model itself.*

• **Estimation**: *w is estimated at any point within the storm's wind field by summing five components due to: topography, boundary layer convergence, storm vorticity changes, baroclinic interactions, and radiative cooling.*

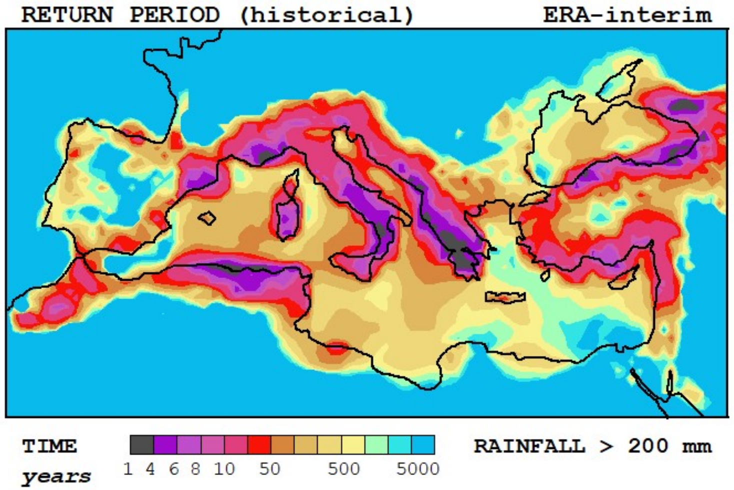


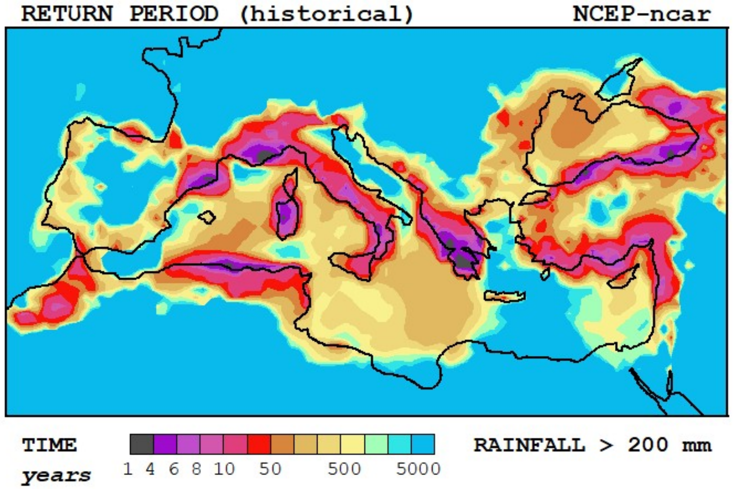


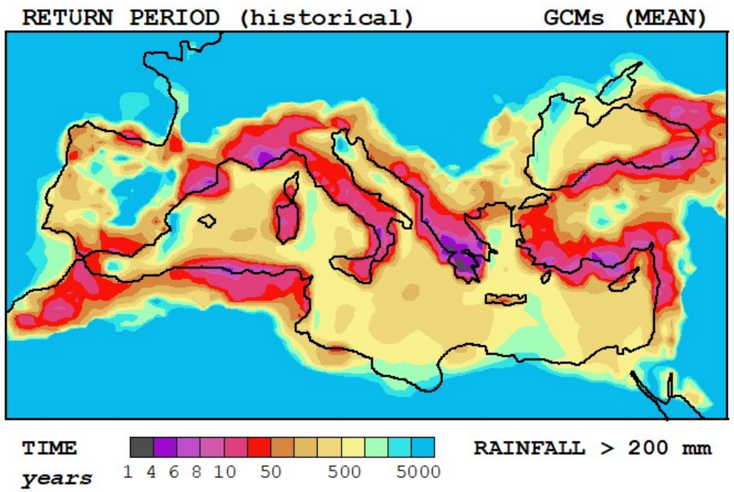
STORM TOTAL RAINFALL

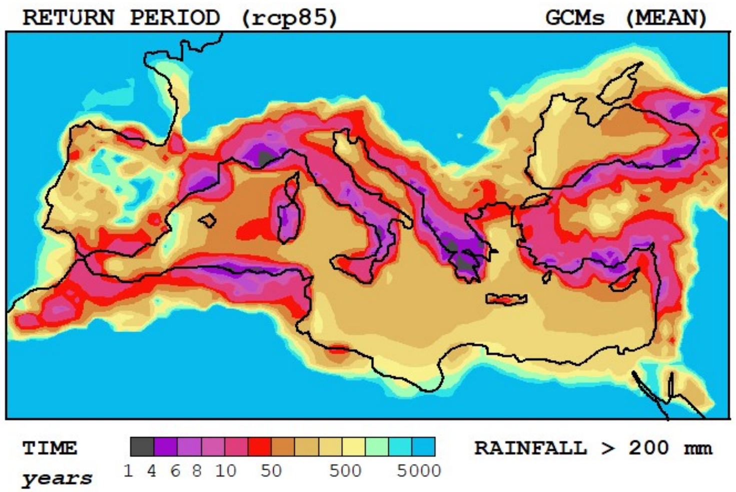
Return Period for

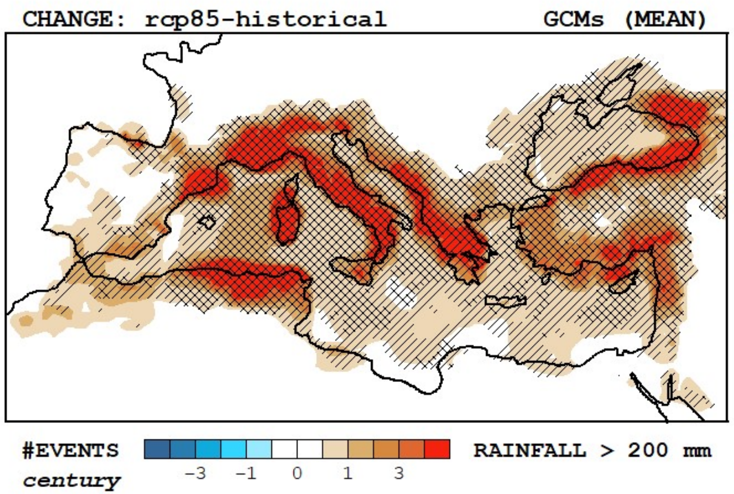
RAINFALL > 200 mm









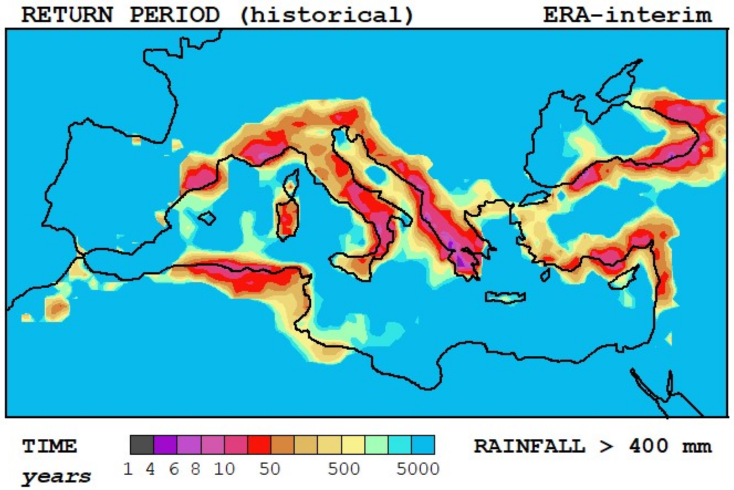


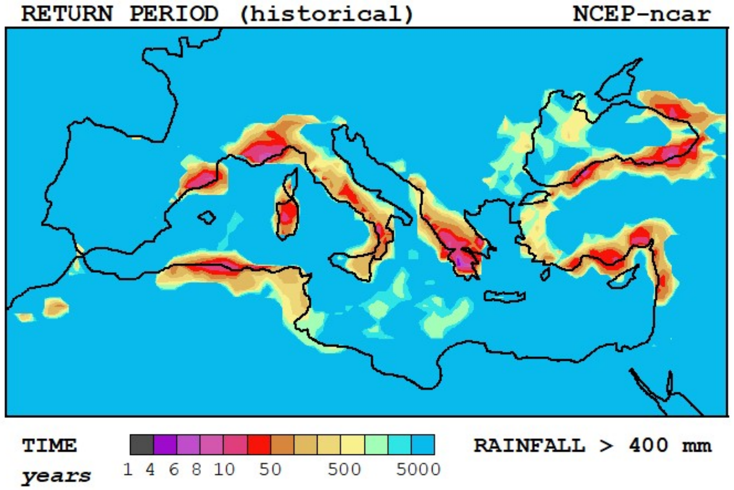
Return Period
200 mm
Summary

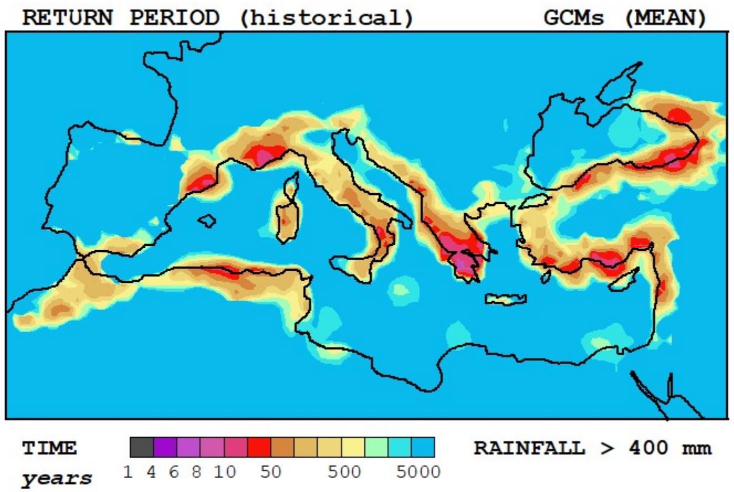
BEST

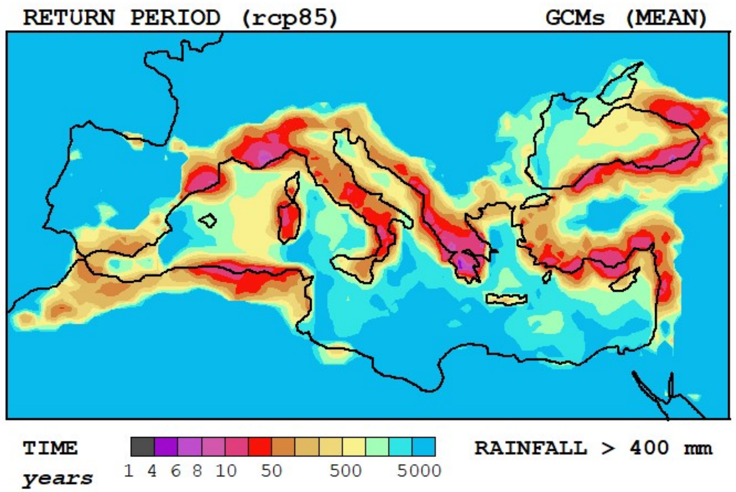
Return Period for

RAINFALL > 400 mm

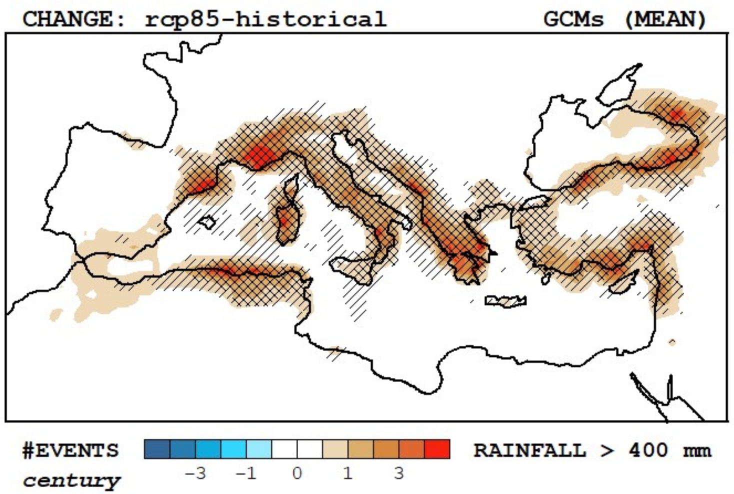








Return Period
400 mm
Summary



BEST

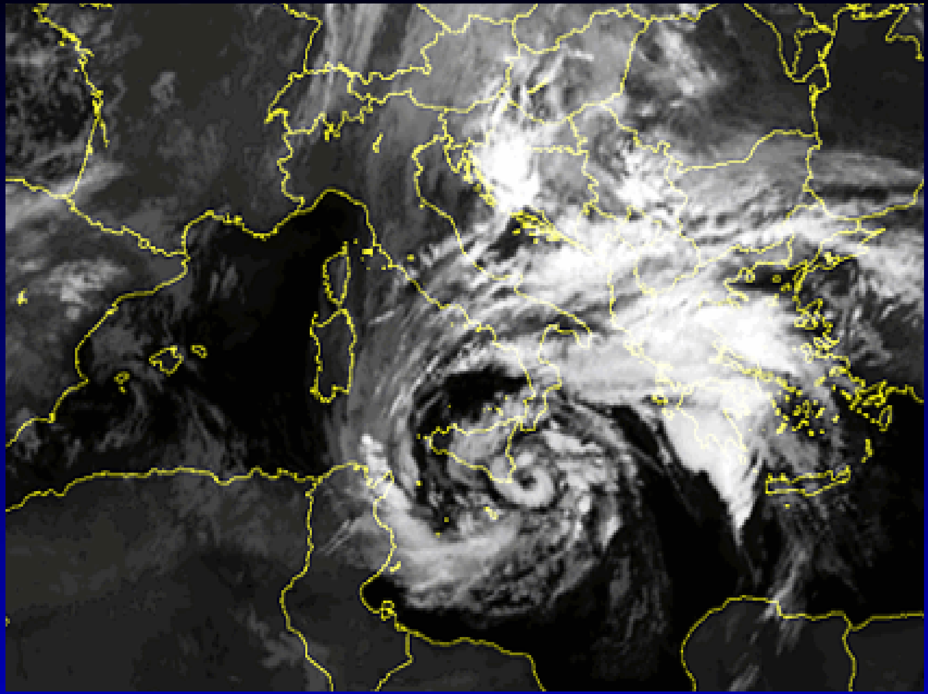
CONCLUSIONS

- *Our statistical-deterministic approach is a good alternative to computationally expensive classical methods (e.g. dynamical downscaling of medicanes), with the extra benefit of producing statistically large populations of events. CMIP6 / 7 ???*

- *Future change in the number of medicanes is unclear (on average the total frequency of storms does not vary) but a profound redistribution is found. Our method projects an increased occurrence of medicanes in the western Mediterranean and Black Sea, balanced by a reduction of storm tracks in contiguous areas, particularly in the central Mediterranean*

- *We found a remarkable modification of the spectrum of lifetime maximum WINDS: the results project a higher number of moderate and violent medicanes at the expense of weak storms. In particular, future extreme events (winds > 60 kt) become more likely in all Mediterranean regions, and the probability of violent medicanes (winds > 90 kt) for the basin as a whole more than doubles the current risk.*

- *The projected intensification of medicanes is mirrored in terms of RAINFALL: future scenarios indicate a notable increase in the occurrence of potentially flood-producing accumulations (e.g. storm total rainfalls exceeding 200 or 400 mm). There is a strong consensus among models that the the current risk will more than double in many coastal areas.*



THANK YOU !!!